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ON THE STRUCTURE OF STEEL INGOTS.

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MUCH has been written concerning the chemical composition of steel ingots, but only small attention has as yet been paid to the internal appearance of the same. The study of the structure of steel is, however, equally as interesting as the study of chemical composition and may throw light on many facts which cannot be explained by chemical analysis alone.

Steel ingots may be faultless as to chemical composition and still give both good and bad results, owing to different modes of casting the metal into the molds.

Some of the faults that are found in ingots are due to purely physical causes, whilst others are derived from the chemical composition.

The defects found in steel ingots may be divided into:

I. Those due to physical causes;

II. Those due to chemical causes; and

III. Those that arise when the steel is heated.

I. PHYSICAL DEFECTS IN INGOTS.

If we split an ingot in the longitudinal direction, a cavity will be found, varying in size according to the general solidity of the metal.

This cavity is called "pipe;" it occurs not only in steel castings, but in castings of other metals, and the higher the melting point of the metal, the larger the "pipe." A few words will explain this.

When a metal of any kind is cast into a cast-iron mold, the outer part, or that part which is in contact with the mold, cools and solidifies whilst the inner part of the metal is yet fluid and hot. The outer part, therefore, by becoming rigid sooner than the inner part, caused the ingot to occupy a larger volume than would have been the case if all parts had cooled equally quickly.

When the cooling takes place concentrically with the mold, a moment will arrive when the solidified outer layers, in the upper parts of the ingot at least, do not longer remain in contact with or receive addition of molten metal, the latter sinking away as the temperature falls, owing to its contraction as well as to its weight.

Therefore, if the ingot is filled in the position indicated Fig. 1, a cavity, A, will be found in the top; and this cavity is larger the higher the melting point of the metal is.

This cavity is not absolutely regular in form, but generally consists of a large cavity A, and several small cavities *aa*.

The large cavity, A, stretches almost

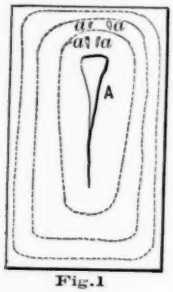

Fig. 1

all the way from the top to the bottom of the ingot, but is of smaller significance in the bottom part, or the part which was cast first.

These central cavities form the "pipe," they are characteristic not for steel only, but for all metal castings. They increase in size with increased melting point and co-efficient of expansion of the metal.

From what has been said it is evident that it must be very difficult to avoid these central defects in steel. We will now show by what means the evil can be lessened.

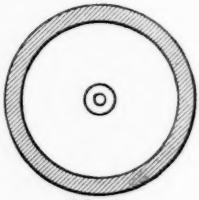

Fig. 2

Let us imagine a perfectly spherical mold, containing fluid steel. It is then evident that, on cooling, a symmetrically-shaped cavity will be formed at the center of the sphere, no regard being taken of the force of gravity acting on the steel, Fig. 2. In reality, however, this cannot take place, because the metal must be poured in through a hole, Fig. 3, and the metal that first comes into contact with the mold is first cooled. The continued inpouring of metal fills up the shrinkages of the first-cooled metal and prevents cavities therein. The force of gravity causes the fluid metal to flow in and fill up any cavities that may have formed. Therefore, when the mold is filled, there will be a layer of first-cooled metal as indicated by the dotted lines, Fig. 3, and the "pipe" will be located somewhat above the center, at *oo*.

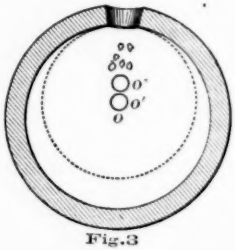

Fig. 3

The position of the "pipe" varies, even for the same metal, with the temperature at casting and the heat-conducting capacity of the mold.

A cast-iron mold should thus be made thicker at the casting hole than at the lower end, Fig. 4. The first layer of cooled metal will then be nearly concentrical with the mold, for the reason that the upper and thicker parts abstract more heat than the lower and thinner parts. The "pipe" will in this case be more centrally located than in a cast-iron mold of uniform thickness.

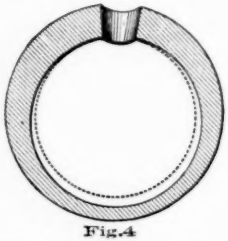

Fig. 4

In general, the "pipe" will be the nearer to the center the less the mold conducts heat, the first-formed layer of chilled metal being thinner. Thus, in a sand mold, the pipe will be more central than in a cast-iron mold.

MOLD MADE OF MATERIALS OF DIFFERENT HEAT-CONDUCTING CAPACITY.

Fig. 6 shows a spherical mold, in which the lower half H consists of cast iron and the upper part (H′) of sand. The dotted lines I, I′, I″, indicate the shape of the chilled layers in this case. The irregular shape is due to the difference in heat-abstracting power between the sand and the cast iron. The "pipe" is here situ-

ated much nearer to the casting hole than if the whole mold had consisted of cast iron.

We will now proceed to describe the various cases that may occur in practice.

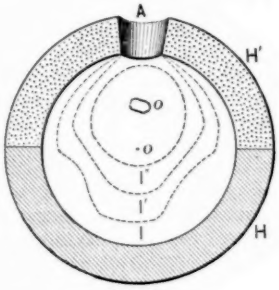

Fig. 6

"PIPE" IN ORDINARY INGOTS.

For ingots that are to be hammered or rolled, the fluid metal is generally cast into slightly conical cast-iron molds, open at both ends, and resting with the larger end upon a cast-iron plate.

When the metal has been cast into the mold, water or sand is thrown on top of the ingot according to the more or less quiet behavior of the metal. Hereby a solid crust is immediately formed, which resists the rising of the steel during cooling. An ingot, on cooling, may become either solid or full of holes (honeycombed). In the former case a small amount of water suffices to produce the solid top-crust. The upper surface cools in the air, whilst the other surface parts of the ingot cool in contact with the sides of the mold. The air has much less power to conduct heat than cast iron; Fig. 7

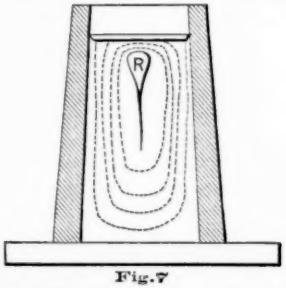

Fig. 7

shows how the cooling in the ingot probably proceeds in this case.

If, instead of letting the steel cool slowly in the mold, the ingot is taken out as soon as the top crust is sufficiently thick, and thrown down, so as to rest upon one of its sides, the "pipe" will obtain the position shown, Fig. 8.

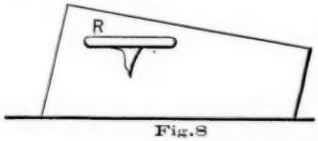

Fig. 8

By turning the ingot upside down, as shown, Fig. 9, the "pipe" is moved to the thicker end of the ingot.

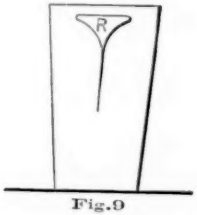

Fig. 9

Sometimes a brick, B, is inserted in the cast-iron plate, Fig. 10, to protect the latter from the destructive action of the stream of metal when casting. In this case it may occur that we find a "pipe" R' in the lower part of the ingot as well as in the upper part, viz.: if the brick be sufficiently large.

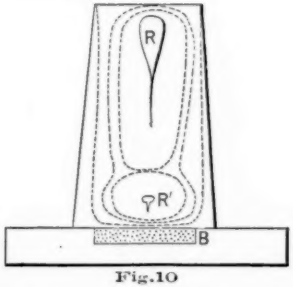

Fig. 10

In all these cases we have supposed that the steel is "cast from the top." Now, let us consider the case when the steel is "cast from the bottom."

Fig. 11 shows how the steel enters the mold from the bottom. When the mold is filled, the hottest steel will, of course, in this case, be in the lower parts, and the colder metal in the upper parts. The

"pipe" R will therefore be found somewhat nearer to the bottom than what would have been the case if the steel had been cast from the top.

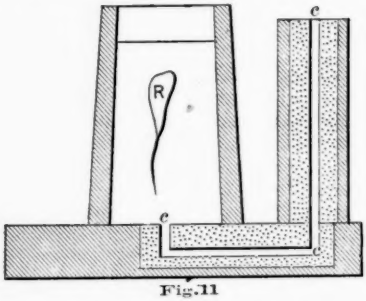

Fig. 11

From what has been said it is obvious that the "pipe" cannot be completely avoided in steel; but its influence on the quality of the metal can be considerably modified, and, in some cases, completely destroyed.

In many cases, where a perfect steel is required, it is necessary to remove that part of the ingot that contains the "pipe." Particularly when hardening steel this becomes necessary, as the steel is sure to crack in that operation if it be internally defective.

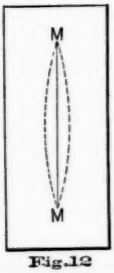

Fig. 12

Suppose we have a forged cylinder of steel, Fig. 12, in which the "pipe" has not been removed, but simply pressed together during the hammering. Let us submit this cylinder to an effective hardening and try to follow the cooling step by step.

As soon as the metal is plunged into the liquid, the outer parts of the cylinder are violently contracted; but, as the inner parts are yet very hot, the outer parts cannot reach the smaller volume which corresponds to the diminished temperature. The outer parts are consequently stretched, and remain in a state of tension. During the second period of the cooling, viz.: when the outer parts of the cylinder give off to the liquid as much heat as they receive from the inner parts, these latter strive to contract; but, as they are intimately combined with the outer parts, which have already become rigid, they are prevented from resuming the volume which they would have occupied if the cooling had taken place in the ordinary way. The inner parts try, in their turn, to contract the outer parts, and finally the whole remains in a state of tension.

Thus, in every hardened piece of steel of the shape mentioned, the outer parts are subject to a compressing, the inner parts to an expanding, strain.

It is evident, then, that the ends MM of the compressed "pipe" may cause ruptures, and it is easy to see that the strains above referred to must weaken the material at these points and make the piece crack.

What has been said regarding the "pipe" can be applied to other similar defects in steel.

THE "SINKHEAD" AS A MEANS OF REMOVING THE "PIPE."

If we investigate the various means for removing the "pipe," the influence of which is so destructive for certain articles, such as steel guns, for instance, we can easily see, from the mode in which the "pipe" is formed, that if the cavities could be filled with molten steel as they form, there would be no "pipe." Unfortunately, it is impossible to accomplish this in practice; but, with the aid of what has been said regarding the casting of steel into molds of different material (Fig. 6), we can come tolerably near the solution of the problem.

Fig. 13 shows a cast-iron mold, placed upon a cast-iron plate. The cast-iron mold has at the top a continuation, consisting of some non-conducting substance. When this mold is filled with steel, and the upper end closed with dry sand, the whole "pipe" will be concentrated in the upper part above the cast-iron mold. If then the part ABCD be cut off, one can be certain of having an ingot free from "pipe."

What now has been said only refers to

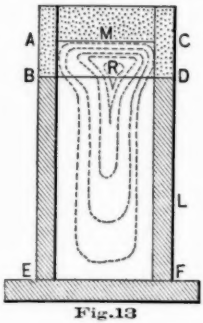

Fig.13

such steel that does *not rise* in the mold after casting.

It is easy to explain the action of the "sinkhead," or that part of the molten metal that is contained in the non-conducting part of the mold. This sinkhead consists of the hottest steel, or the steel that came last from the ladle or furnace, and is prevented from cooling by the sand and the non-conducting part of the mold. Fluid steel, therefore, flows down and fills the cavities in the ingots as they form. The ingot thus becomes solid, whilst the sinkhead is full of holes.

The sinkhead need not be very big, as compared with the ingot, if it only be wide enough, so as not to become rigid before the formation of cavities in the ingot has thoroughly ceased. Otherwise two "pipes" will be formed, one in the head and one in the ingot, Fig. 14.

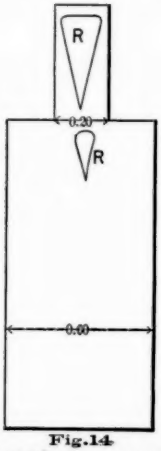

Fig.14.
Insufficient Sinkhead. 200 Kg. Ingot.

20 % of the height of the ingot should be taken as sinkhead; this does not, however, correspond to 20 % of the weight of the ingot, as the sinkhead is nearly empty.

PRECAUTIONS TO BE TAKEN IN ORDER TO MAKE THE SINKHEAD EFFECTIVE.

It should be borne in mind that what has been said above does only apply to such steel that stands quietly in the molds without evolution of gas. The case of rising steel will be considered below.

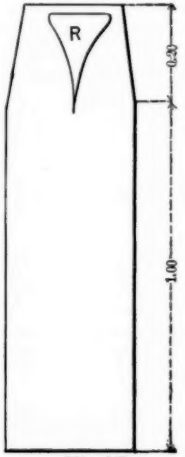

Fig.15
Sufficient Sinkhead. 1200 Kg. Ingot.

The sand in the sinkhead should be sufficiently refractory not to melt in contact with the hot steel; otherwise the slag thus formed reacts on the steel so as to cool and impede the useful action of the sinkhead. The sinkhead-mold must be perfectly dry before pouring in the metal; the moisture would, if present, cause too rapid cooling.

The sinkhead should have as nearly as possible the same transverse dimensions as the ingot, and its height must not be less than 20% of the total height.

Casting from the bottom must be avoided, because such casting brings the colder metal to the top. When the mold is so high, however, that casting from the top would injure the bottom-plate, the casting may be commenced from the bottom and completed from the top.

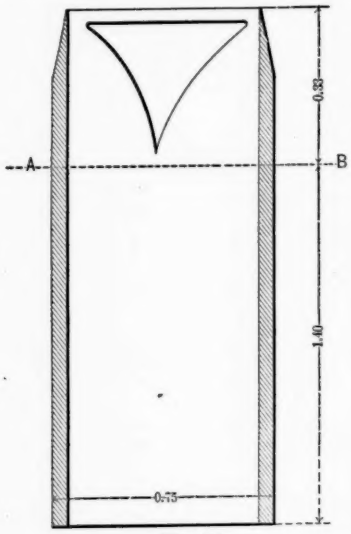

Fig 16

ANOTHER MODE OF USING THE SINKHEAD.

It is not absolutely necessary to make the sinkhead-mold of sand. For small ingots another method may be used; it is not quite so efficient, but in many cases useful.

The method consists in having a mold, as shown in Fig. 17, resting with its *narrower* end on the bottom-plate. The thickness of the sides of the mold is decreasing upwards. The metal is tapped direct into the mold from the top. As is seen from Fig. 17, an upper layer AB acts as sinkhead for a lower layer CD. The metal in AB reached the mould later than the metal in CD, and is consequently hotter. The sides of the mold being thicker towards the lower end more heat is lost by conduction in CD than in AB. Finally, AB being larger than CD, the former cools slower than the latter. For these reasons the metal in the upper part of the mold must be hotter than the metal underneath, thus acting as sinkhead for the latter.

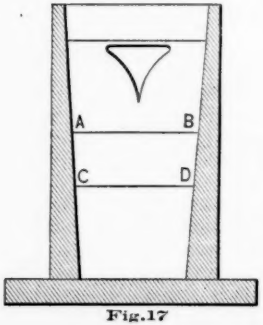

Fig.17

If dry sand be put on top of the steel, the upper part of the ingot will remain superheated sufficiently long to cause the whole "pipe" to concentrate there completely.

MEANS FOR DISTRIBUTING THE "PIPE" THROUGH THE WHOLE MASS OF THE INGOT.

In certain cases it is suitable to have the "pipe" spread through the whole mass of steel instead of concentrating it in the upper part.

The method for doing this, which we will now mention, has only a limited usefulness, but may be applied in certain cases.

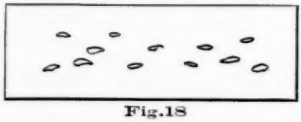

Fig.18

Suppose the ingot to be taken out of the mold and laid upon one of its larger sides. The "pipe" will then occupy the position indicated, Fig. 8, after cooling. If, however, instead of allowing the ingot to cool undisturbedly, we keep rolling it over and over, it is evident that the "pipe" must be split up and distributed throughout the steel, Fig. 18.

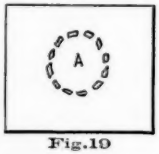

Fig.19

The ingot need not be revolved very rapidly, but the motion must be kept up as long as the metal remains fluid; otherwise the central parts of the ingot will be almost separated from the rest, Figs. 19, 20. This has been confirmed by experience.

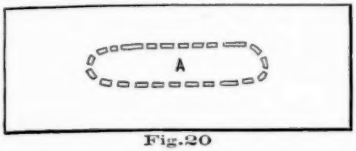

Fig. 20

INFLUENCE OF THE "PIPE" ON CERTAIN FORGED AND ROLLED ARTICLES.

Everybody who has had to do with the rolling of steel rails knows that the end of the rail sometimes shows a crack, R, Fig. 21; this crack is often situated in the web or stem of the rail.

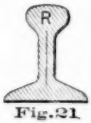

Fig. 21

This crack is due to the "pipe," the sides of which have not welded together during rolling. Such a rail is apt to break at one single impact. The crack in question may often exist in the rail without being visible at the end.

If the "pipe" should happen to occupy the position indicated, Fig. 8, the crack will probably be found in the head or in the foot of the rail.

Doubtless many rails have broken on account of said crack, and not in consequence of some slight deviation from the chemical composition ordinarily used.

Fig. 22

In tyres the effect of the "pipe" is different. When punching the hole in a round tyre-ingot, it may happen that only part of the crack R, Fig. 22, is removed. In this case a line, R, remains on the inside of the tyre, Fig. 23.

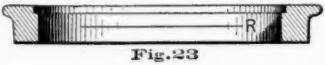

Fig. 23

Such a tyre, after being in service for some time, generally splits in two.

In the manufacture of axles it often happens that too small ingots are used. In this case a crack, due to the "pipe," is

Fig. 24

likely to occur in one end of the axle, Fig. 24, whilst the other end is perfect.

"PIPE" IN STEEL THAT "RISES" DURING COOLING.

Some steels, poor in silicon, when tapped at a certain temperature, continue to rise in the mold for some time immediately after casting.

Whatever be the cause of this phenomenon, it is a fact that it occurs chiefly in soft Bessemer and Siemens-Martin steel.

When such metal is cast into a mold a solid crust is formed where the metal touches the sides of the mold, whilst in the interior gas is being evolved, keeping the fluid metal in a state of agitation. It is probable that, owing to this agitation, the temperature is pretty uniform through the whole mass, and that therefore the "pipe" in this case will not be concentrated exclusively in the top, Fig. 25. The evolution of gases gives rise to

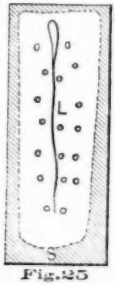

Fig. 25

a number of blow-holes and cavities, thus rendering the ingot unsound. It is evident that the sinkhead is of little use in a case of this kind. The sand, which is used to form the top of the sinkhead, may be drawn into the bubbling mass, where it melts and mixes with the steels, giving rise to violent reactions and explosions. If, therefore, it be desired to use a sinkhead for a rising metal, the sinkhead-mold should be made out of cast-iron, surrounded by sand to prevent the abstraction of heat, Fig. 26. Thus arranged, the sinkhead may be of some use, even for rising metal.

We may now condense what has been said concerning the "pipe," as follows:

1. The extent and importance of the "pipe" is greater the higher the temperature at casting.

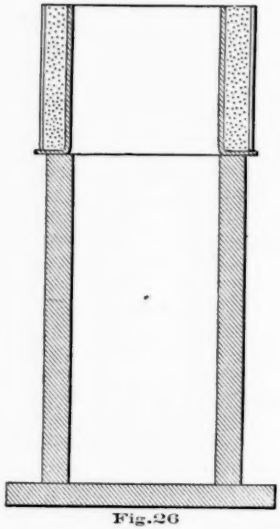

Fig. 26

2. The "pipe" is larger in "quiet" steels than in "rising" steels; in the latter the "pipe" is more evenly distributed through the whole mass, and gives, therefore, less trouble in cases where it is desired to use the *whole* of the ingot.

3. The "pipe" may be concentrated in the upper part of the ingot by promoting the cooling of the lower parts of the ingot and keeping the upper part at a high temperature.

At the exhibition, 1878, Sir Joseph Whitworth exhibited ingots that had been compressed after tapping. These ingots did not show any traces of "pipe," although a "pipe" ought certainly to have been there. Compression being nothing but a kind of forging, it is probable that the lips of the "pipe" had been very closely compressed, so as to leave no lines visible to the naked eye; after polishing and etching with acid it is probable that the steel would have shown marks of the "pipe."

It is, in fact, impossible to entirely remove the pipe; one can only lessen and counteract it by the means above shown.

SURFACE CRACKS ON INGOTS.

When looking closely at an ingot of sufficiently large dimensions, we often discover some cracks, some running transversely or horizontally across, and some lengthwise along the ingot. These cracks are often quite small; they may, nevertheless, cause serious difficulty in hammering and rolling the steel.

The horizontal cracks are generally due to resistance to contraction during cooling, such, for instance, if the ingot stick to the side of the mold in one or more places.

Slightly conical ingots are less apt to crack horizontally than those that are of equal thickness throughout.

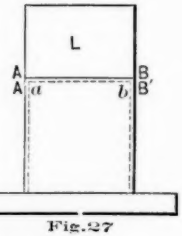

Fig. 27

The explanation of this is easily found. Fig. 27 shows a cylindrical mold; Fig. 28 a conical mold. The sections AB and $A_{11}B_{11}$ contract to ab and $a'b'$ on cooling. Thus, if $AB=A_{11}B_{11}$ we have $AB-ab=A_{11}B_{11}-a'b'$. But whilst $AB=A_1B_1$, we have $A_{111}B_{111}>A_{11}B_{11}$ and $A_{111}B_{111}-a'b'>A_1B_1-ab$. Consequently, in the conical mold the ingot is further from the mold after cooling than in the cylindrical mold, and thus less apt to stick.

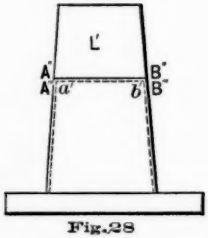

Fig. 28

A suitable conicity for a mold is 25 mm. in one meter.

The principal causes of horizontal cracks are—1st, defective molds; 2d, too hot metal; 3d, suspension of the ingot-top, caused by the metal either flowing over

the edge of the mold or squeezing itself between the stopper and the mold; and, 4th, a defective bottom plate.

The molds must be carefully watched and rejected as soon as they are found defective. Care must be taken not to let the metal strike the sides of the mold when casting, as otherwise cold skins may be formed and the mold eaten out.

Casting from the bottom, as a rule, gives ingots of a better appearance, and more free from horizontal cracks than casting from the top, the metal in the former case rising quietly without being thrown up against the sides of the mold. The coldest metal is at the top, causing the shrinking to begin there; in this way at least one cause for the cracks is removed, viz., the influence exerted by the force of gravity, when the ingot, after having shrunk together at the bottom, remains suspended by the top part, which still sticks to the mold.

Longitudinal cracks may, like horizontal cracks, be due to resistance to shrinking, but, as a rule, they are due to quite a different cause, viz., the pressure exerted on the lower parts of the ingot. A cylindrical ingot is particularly liable to crack from this cause, Fig. 29; such ingots are therefore difficult to make. A square ingot is better, but as the square ingots generally have rounded corners, they are apt to crack longitudinally at those.

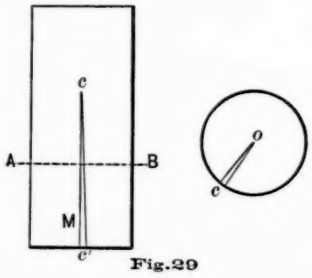

Fig. 29

Casting from the bottom promotes longitudinal cracking, the hottest metal being at the bottom; thus the bottom crust, which has to resist the pressure of the superimposed metal, is weaker than if the metal had been cast from the top. Too rapid casting also promotes longitudinal cracks.

To avoid longitudinal cracks it is therefore necessary—

1st. To give the ingot throughout its whole length such a section as will permit of change of form.

2d. To cast as slowly as possible.

3d. To use the bottom cast as little as possible.

II. Defects due to Chemical Causes.

When examining the fracture of a steel ingot we generally find a large number of small cavities, more or less irregular in shape, some spherical, some oval, and some formed through the combination of several surfaces. Some of these cavities have a pure metallic, silver-white surface, others are colored through oxidation, which shows that they must, at a certain moment, have been in contact with the air; others may be covered with a brown coating,* the cause of which we have not been able to find out.

These cavities, or blowholes, are generally symmetrically grouped in regular geometrical figures; sometimes, however, they are quite irregularly distributed.

When steel is poured into a mold, we see a large quantity of gas being evolved, and more so the softer the metal. Some claim that this gas consists of carbonic oxide; others say it is hydrogen.†

Of late years this matter has caused a good deal of discussion; we, for our part, believe that the gas evolved during the cooling of the steel is simply carbonic oxide, the ingredients of which gas exist in large quantities in the molten steel. For many reasons it is difficult to believe that this gas would be hydrogen. Bessemer metal is generally more free from blowholes than is Siemens-Martin metal, although the former ought to have more hydrogen, owing to the mode of manufacture. And how explain the influence

* When HCl. is poured into a blowhole thus coated, the brown coat is instantly removed with evolution of H_2S.

† After the publication of Dr. Muller's works concerning the gases in ingots, we repeated the principal tests which he made in order to show that steel mechanically occludes hydrogen.

As well known, Muller's experiment consists in boring ingots under water and collecting the gas thus set free.

We found that gas always was obtained when water was used, whilst not a trace could be found when mercury or oil was employed.

The reason for this is not difficult to conjecture. The drill is magnetized by the rapid revolutions, and causes an electric current, which decomposes the water. The gas thus obtained detonates without any extra addition of air and gives water.

of silicon upon the suppression of the blowholes if the latter be due to hydrogen? It is, nevertheless, an established fact that the presence of silicon in steel causes the almost entire disappearance of the blowholes.

It is easy to explain the relation between silicon and dissolved oxides, but it is difficult to see how silicon can lessen the influence of dissolved hydrogen.

We believe that the hydrogen theory has no more foundation than the old theory which claimed that nitrogen was the element that determined the qualities of the steel.

THE DEVELOPMENT AND POSITION OF THE BLOWHOLES IN INGOTS.

Two circumstances exert the greatest influence on the formation of blowholes in ingots, viz., the chemical composition of the metal, and the temperature at which the casting takes place.

Let us suppose that the metal be entirely free from silicon, and that the casting temperature be what we may call normal. A little carbon and oxide of iron always occurs in the metal, whether it be made in a Bessemer or a Siemens-Martin furnace. The respective quantities of these bodies change necessarily with the softness of the metal; the harder the metal is, the more carbon and the less oxide of iron is present in it. We may even say that in hard steel there is no oxide of iron at all, owing to the large quantity of carbon, which reduces the oxide as soon as it forms.

If we investigate how such a steel behaves in the molds immediately after casting, we find that the surface is moved by a slight bubbling, which lasts only a little while, the ingot soon covering itself with a crust or skin, which closes itself entirely. During this bubbling blue flames, resembling the carbonic oxide flame, are emitted; these flames cease when the crust has formed. The fracture of an ingot of this kind shows the blowholes arranged, as indicated by Fig. 30, on a parallel line with the sides of the mold. It is easy to see how these blowholes are formed. When the steel is poured into the mold the metal next to the sides of the mold is cooled, and a layer of nearly rigid metal is formed. No blowholes can be formed in this layer, as the metal inside is kept in agitation by escaping gas, thus filling up any cavities that may form. But when bubbling ceases, *i. e.*, when the top crust has been formed, the reaction between the carbon and the dissolved oxides continues during the cooling period, and carbonic oxide is generated through the whole molten mass. The blowholes, which form in the parts which are yet in a molten state, ascend to the surface, and the gas contained in them either breaks through the crust or passes into the "pipe." On the other hand, the gas that forms in the not-longer fluid part of the steel cannot ascend, and remains in regular lines as shown, Fig. 30.

Fig. 30

But why is it, then, we may ask, that, with the exception of this belt of blowholes, the inner part of the ingot is quite sound and solid? This can be explained in two ways:

1st. The metal remains fluid long enough to enable the carbon to reduce all the oxides of iron compounds, and to escape as carbonic oxide.

2d. The evolution of CO causes sufficient internal pressure to suppress continued evolution of gas, which therefore remains dissolved in the metal.*

The explanation No. 2 seems to us the most probable, because it has been shown that even a moderate pressure can considerably diminish the evolution of gas in a certain metal.†

When the amount of carbon is small, and consequently the amount of dissolved oxygen is larger,‡ the period of bubbling

* There ought to be an analogy between the evolution of gas in fluid steel and that in a soda-water bottle. If we watch the bubbling in a glass of soda-water, we find that 90% of the bubbles rise from the circumference.

† We have cast several ingots under 5 to 6 atm. pressure; these ingots had always less blowholes than ordinary ingots.

‡ Possibly the actual amount of dissolved oxygen is not larger in this case, but the amount of carbon present being small, the reaction between the two elements takes place more slowly; the period of bubbling is therefore longer. Sometimes, however, a larger quantity of dissolved oxygen has really been found in the soft steels than in the hard ones.

immediately after casting lasts longer. In this case the belt of blowholes may be found farther in than shown in Fig. 30, *vide* Fig. 31. In every low-carbon steel,

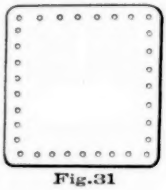

Fig.31

such as boiler-plate, etc., the bubbles may be found still farther in, Fig. 32.

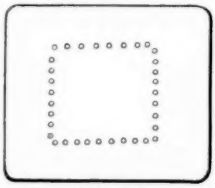

Fig.32

The explanation is always the same, viz., that blowholes cannot continue to exist as long as the metal is in motion.

These experiences have been chiefly derived from the steels obtained by the basic Bessemer process, in which there is no silicon to counteract the formation of blowholes, but the above is equally applicable to certain Bessemer steels that have been obtained by complete decarburization and recarburization, and more especially to Siemens-Martin steel, which has comparatively little silicon.

At the beginning of this chapter we mentioned that the chemical composition of the steel had a great influence on the formation of blowholes. The presence of silicon prevents their formation very effectually.

Manganese alone cannot prevent blowholes, as shown by experience.

Silicon and manganese combined remove the blowholes almost completely, an easily fusible silicate of MnO or of FeO+MnO being formed, which slag easily separates from the molten metal.

By the addition of a very silicious pig, that metal free from blowholes is obtained, which has caused such frequent discussion during the last years. Bessemer already mentioned this fact at the introduction of his process.

Everybody has seen or heard of the famous solid castings from Bochum and Terrenoire, etc. All these objects have been obtained by making use of the powerful oxygen-absorbing properties of silicon, when mixed with a bath of molten steel, containing oxidized iron.

Bessemer and Siemens-Martin steel behave somewhat differently according to the amounts of silicon and manganese in the pig iron used. But notice must also be taken of the temperature of casting the metal.

Let us suppose that the temperature of the steel, without being *too* high, is sufficiently high to prevent the formation of any scrap in the ladle. The temperature may then be called normal, and every steel-maker soon learns to know the same. If a pig iron, with a moderate percentage of manganese (2 to 3%) be treated under these conditions, and the oxidation not driven too far before carburizing with spiegel or ferromanganese, a product is obtained, which may be cast exactly like pig iron, and therefore gives ingots free from blowholes.

The metal need not be very rich in carbon. As soon as the carbon exceeds .3 every casting will succeed, if the temperature be the right one. With less carbon the difficulties become greater, and special precautions are required to prevent oxidation.

As regards silicon, the unfavorable influences of the same during rolling and forging is well known; it may be lowered to .1 to .15. Between these limits its presence is rather of use than otherwise, particularly if the steel contain sulphur.

If the temperature at the casting of the steel into molds be too low, as well as if the heat developed during the operation be insufficient,* the metal contains a certain quantity of iron oxides, which react on the carbon during cooling, and form CO.

Unless the temperature be *entirely* too low, the metal in contact with the mold solidifies through a thick layer, but remains fluid internally. A belt of large

* Iron seems to oxidize easier at lower than at higher temperatures; for this reason, soc. "cold" metal contains little silicon and manganese, owing to the presence of oxide of iron.

blowholes is formed as shown, Fig. 33, nearly extending to the edge. Such metal generally stands quietly in the molds, covering itself with a symmetrical skin.

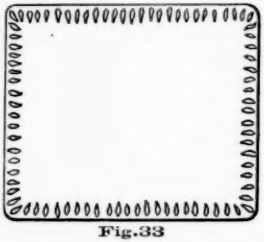

Fig.33

If the oxidation for obtaining a soft metal has been driven very far, the ingot has the fracture shown in Fig. 34. The metal behaves like soft metal free from silicon.

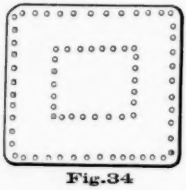

Fig.34

If the metal be cast at a very low temperature, it becomes "pasty" throughout when poured into the mold. The result is a spongy metal—Fig. 35. If the metal at the same time be very soft, it rises vio-

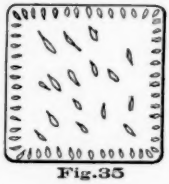

Fig.35

lently in the molds and recedes alternately; finally it sinks back, giving ingots of which only the lower parts can be used, Fig. 36. Sometimes the upper part of such an ingot is closed, so that the whole, externally, resembles a solid ingot.

It should be remembered that the normal tapping temperature is higher for

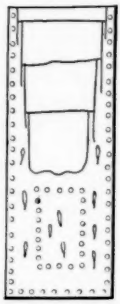

Fig.36

soft metal than for hard metal, the melting point being higher in the soft metal.

In the Bessemer process it sometimes happens that the temperature rises too much. Metal thus obtained must be altogether rejected, because, besides many physical faults, such metal generally is extra rich in silicon, probably owing to a continued reduction of silicon from the walls of the converter by carbon or iron. It would seem as if such silicious metal ought to be free from blowholes; and yet, if it be cast at once, when ready, it gives ingots at least as honeycombed as ingots made of cold hard steel. But the nature of the blowholes is entirely different. The fracture of such ingots shows the edges perforated by innumerable small, narrow, very elongated, and closely-packed blowholes, Fig. 37.

Fig.37

Such ingots very seldom behave well during rolling and forging, the product almost always becoming cracky and full of unsoundness, due to compressed blowholes.

Now it would seem from this as if the theory of silicon as a remedy for blowholes would not hold good in this case; such is, however, not the case. That special kind of blowholes indicated by Fig. 37, has nothing to do with the chemical composition of the metal. If we polish the surface of an ingot that has been

cast too hot, we will find that ends of the blowholes in question run right out to the circumference. Ingots of this kind are also difficult to get out of the molds, which shows that they stick to the sides of the molds during a large part of the time required for cooling.

The cause of the special kind of blowholes, shown Fig. 37, is an external one, so to speak. The molds are always more or less oxidized; the reaction between the oxides of the molds and the molten metal causes evolution of CO, which, being unable to pass up between the mold and the ingot and the fluid metal, forces its way into the latter, forming blowholes as shown Fig. 37.

These blowholes have given so much annoyance that we have been induced to make some experiments in order to throw some more light on their origin. We polished a cast-iron mold until it presented a perfectly metallic surface. We then cast into this polished mold superheated Bessemer metal, at the same time casting such metal into an ordinary mold, for comparison. The ingot obtained in the polished mold was perfectly sound, whilst the ingot obtained in the ordinary mold had the appearance of overheated metal, just described.

Siemens-Martin steel is less liable to become overheated than Bessemer metal.

When the temperature at the beginning of a tap is very high, the first ingots may be defective, as per Fig. 37, whilst the last ingots may be sound, owing to gradual cooling of the metal.

III. Precautions to be Observed to Avoid Defects Resulting from the Heating of the Steel.

When a cold ingot is placed in a very hot furnace one may often hear sharp reports, indicating internal ruptures in the steel.

This is due to too rapid heating. Hard steels and steels rich in silicon are particularly sensitive to such heating.

When an ingot is placed in a too hot furnace, the exterior expands before the interior is sufficiently warm to follow. If the steel has only small power of elongation, the stretching forces may therefore rupture the interior. If such an ingot be fractured, a circular rupture will generally be found, Fig. 38. When such an ingot is rolled out this rupture will be transformed into a longitudinal hole, Fig. 39, which is not always visible from the outside, thus involving considerable danger.

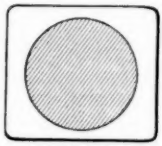

Fig. 38

At the time when the manufacture of large objects of forged steel was in its infancy, one used to ridicule the great secrecy with which Krupp surrounded his methods of heating large ingots; but we are now compelled to admit that Krupp's precautions were the result of a long experience.

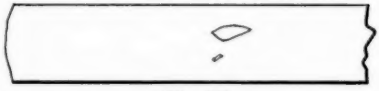

Fig. 39

If we wish to protect ourselves against this kind of defect in steel, we must thus observe the following precautions:

1. Never to let an ingot cool completely before putting it into the hot furnace.

2. If it be necessary to use cold ingots, to heat them very gradually. Such large ingots as are intended for guns, shafts, etc., are best placed in a cold furnace, which is then slowly heated up. Small ingots are best heated in a long furnace, in which the ingots can be gradually pushed up towards the hottest part.

A paper was recently read before the Paris Academy of Sciences on the electric conductibility of solid mercury and of pure metals at low temperatures, by MM. Cailletet and Bouty. From numerous experiments made with mercury, silver, tin, aluminium, magnesium, copper, iron, and platina, the authors conclude that the electric resistance of most pure metals decreases regularly when the temperature is lowered from 0 deg. to −123 deg., and that the coefficient of variation is apparently much the same for all. It seems probable that the resistance would become extremely slight at temperatures lower than −200 deg., although this point has not yet been practically tested.

PRINCIPLES OF FORECASTING BY MEANS OF WEATHER CHARTS.

By the Hon. RALPH ABERCROMBY, F.R. Met. Soc.

From the "Nautical Magazine."

The Meteorological Council has issued a work on "Weather Forecasting," by the Hon. Ralph Abercromby. It gives an insight into the secret working of the forecaster, and contains a fund of information for those who aim to be weather wise. The modern method of forecasting, by combining on a chart the weather observations made at the same instant of time at a large number of places, has only been introduced within the last twenty-five years. Prior to this the forecaster was limited to isolated observations of the barometer, and to such popular weather signs as the appearance of the sky or the movements of animals.

The forecast now issued by the Meteorological Office are based upon the telegraphic reports from upwards of fifty stations, which represent not only the entire area of the British Islands, but extend along the entire western coast of the continent of Europe, from Christiansund, in latitude 63° N., to Corunna in latitude 43° N., and include four stations on the coast of the Baltic, and one in the Mediterranean. The height of the barometer and thermometer, with the direction and force of the wind, together with the actual state of the weather conveyed in these telegrams, are charted immediately on their receipt, and from an examination of a series of these charts the necessary deductions and conclusions are drawn.

The work gives instructions in the numerous intricacies involved in the art of manufacturing weather forecasts. It is not, however, possible with our limited space to touch on all the various problems placed before us, but it will be useful to indicate the outline of the information conveyed, keeping as far as possible to the author's words.

CYCLONES.

The technical terms referring to cyclones are first explained:—

The center of a cyclone is the geometrical center of the innermost isobar, or line of lowest barometer.

The diameter of a cyclone is a line drawn through the center as far outwards as the curvature of the isobars is distinctly related to the center, and is often very ill-defined, since the influence of the cyclone extends much further in some directions than in others. A cyclone may be of any diameter, from 100 to 3,000 miles. The commonest are between 1,000 and 2,000 miles; and anything less than 1,200 miles across may be called a small one. The diameter is the measure of the size of a cyclone.

The axis of the cyclone is an imaginary line round which the whole air in a cyclone may be supposed to circulate. There is reason to believe that it is not usually vertical to the earth's surface, and that both the inclination and direction of the axis is variable.

The intensity of a cyclone is measured by the maximum steepness of the barometrical gradient in any portion of it. If this exceed 0.02 inch per15 nautical miles, then the cyclone may be said to be of considerable intensity.

By the expression the level of a "cyclone" is meant the barometrical reading at the lowest point. If the lowest point in the cyclone is above 29.9 inches, we may call it a high-level cyclone; if below that, a low-level one.

The path of a cyclone is the path described by the center. In this country 90 per cent. move towards some point of east, the most frequent direction being about east north-east.

The velocity of a cyclone is the velocity of the center. It may be anything from 80 miles an hour eastward to 10 miles an hour westward. About twenty miles is a common velocity, but sometimes a cyclone is stationary.

The trough is a line drawn through the center of the cyclone, generally at right angles to its path, which marks out the position of all the places where the barometer has attained its lowest point. Everywhere the mercury is falling in front and rising in rear of the line, in

consequence of the forward motion of the cyclone. This line defines the front and rear of a cyclone.

The right and left sides of a cyclone are the right and left sides to an observer looking in the direction in which the cyclone advances; they are thus relative to the direction of the cyclone path.

The life of a cyclone is measured by the number of days during which it can be traced on synoptic charts. The length of the life may be anything from a few hours to about twenty days. Any cyclone whose life is less than 24 hours may be called short-lived.

With respect to the details of wind, weather, temperature, &c., in different portions of a cyclone:—

The temperature is always higher in front than in rear; the warm air in front having a peculiarly close muggy character, quite independent of the actual height of the thermometer. The cold air in the rear, on the contrary, has a peculiarly exhilarating feeling, also quite independent of the thermometer.

The front is always very damp, especially the right front, while the rear is dry to a marked degree.

The wind blows round the center in a direction contrary to the motion of the hands of a watch, which is lying horizontally with its face upwards; but as the direction is slightly inclined to the isobars, on the whole the circulation is an in-going spiral. The amount of incurvature is usually greatest in the right front and least in the rear of the cyclone, so that sometimes the passage of the trough is marked by a sudden shift of wind.

The grouping of the weather into types is somewhat new, and has been undertaken by Mr. Abercromby expressly for this publication.

WEATHER TYPES.

The general idea of weather types will be readily understood by considering the fact familiar to all observers, that the weather in this country frequently occurs in spells of several weeks' duration, during which there is a remarkable persistence of the general type of weather overriding both a considerable fluctuation from day to day, and a considerable local variation from place to place.

For instance, the wind will often back to some point of south, with a high temperature, a dull sky and rain, and then veer to some point of west, with a cooler air and brighter sky; and after a day or so of fine weather it will back again to the south with bad weather, perhaps this time rising to the intensity of a gale, and subsequently veer towards the west with finer weather, and so on for weeks together.

The changes only vary in intensity and detail, not in general character, while the feel of the weather and the look of the sky remain through all of them characteristic of westerly winds.

Similarly, the wind will often come persistently frome some point of east, fluctuating between south-east for fouler weather, and north-east for finer weather, and back again with many variations for several weeks, during which the predominant features of the weather are always characteristic of east winds. The frequent recurrence of particular types of weather at particular seasons of the year is also a matter of common observation; the north-east winds of March, the cold north winds in the middle of June, and the wet west winds of September are well-known instances.

If we examine a large number of synoptic charts, we soon see that relatively to Europe, the general position of the great areas of high pressure frequently remained constant for a lengthened period. Further examination shows that the constancy of these positions coincides with persistency of types of weather similar to those above mentioned, the fluctuation of weather in each type being due to the passage of cyclones, while the local variation depends on the exact position of the cyclone center, and on the innumerable local conditions which modify any general type.

The types may be considered as applying generally to Europe, while the details of weather refer only to Great Britain.

The distribution of atmospheric pressure for the Northern Hemisphere presents certain constant features; namely:

1. An equatorial belt of nearly uniform low pressure.

2. A Tropical belt of high pressure rising at intervals into great irregular elevations or anticyclones.

3. A temperate and Arctic region of generally lower pressure, but in which oc-

casionally areas of high pressure appear for a considerable period.

The equatorial belt constantly covers the Sahara and the Amazon Valley, and always narrows over the Atlantic at about 30° west longitude, where it often does not reach higher than 10° north latitude. The shape and depth of this area are tolerably constant.

The Tropical belt comprises a region of high pressure, rising at variable intervals into great anticyclones; these anticyclones are usually longest in an east and west direction, and often rise into two or more heads. Their position is generally variable with the exception of one, which is always found over the central Atlantic. This anticyclone forms a very important factor of the weather of Western Europe, and will be constantly referred to as "the Atlantic Anticyclone."

The extension south and west of this anticyclone is tolerably constant, while north and east it is variable, sometimes rising as far as 60° north and stretching over Great Britain and Continental Europe.

Cyclones are rarely, if ever, formed to the south of this anticyclone; sometimes they have their origin on its south-west side, when they work round the anticyclone first towards the north-west, and then towards north-east. These are the West India Hurricanes.

The north side of the anticyclone is the birthplace of innumerable cyclones of every size and intensity, which invariably move towards some point of east, and then play a most important part in the meteorology of Great Britain.

Cyclones are also occasionally formed on the south-east side near Madeira; these either work very slowly round the high pressure to the south-west, or else leave the anticyclone and go east.

The Temperate and Arctic region extends from the tropical high pressure to the pole. Though ordinarily low, the pressure in this region is perpetually fluctuating by reason of the incessant passage of cyclones; yet occasionally persistent areas of high pressure appear in certain portions of it.

With reference to Western Europe, there are at least four well-marked types of weather:

1. The Southerly, in which an anticyclone lies to the east or south-east of Great Britain, while cyclones coming in from the Atlantic either beat up against it or pass towards north-east.

2. The Westerly, in which the tropical belt of anticyclones is found to the south of Great Britain, and the cyclones which are formed in the central Atlantic, pass towards east or north-east.

3. The Northerly, in which the Atlantic anticyclone stretches far to the west and north-west of Great Britain, roughly covering the Atlantic Ocean. In this case cyclones spring up on the north or east side, and either work round the anticyclone to the south-east, or leave it and travel rapidly towards the east.

4. The Easterly, in which an apparently non-tropical anticyclone (or one disconnected from the tropical high-pressure belt) appears in the north-east of Europe, rarely extending beyond the coast line, while the Atlantic anticyclone is occasionally totally absent from the Bay of Biscay. The cyclones then either come in from the Atlantic and pass south-east between the Scandinavian and Atlantic anticyclones; or else their progress being impeded, they are arrested or deflected by the anticyclone in the north-east of Europe.

Sometimes they are formed to the south of the north-east anticyclone, and advance slowly towards the east, or in very rare instances towards the west.

SOUTHERLY TYPE.

In this the Atlantic anticyclone extends very little to the northward, while a large area of high pressure covers Europe to the east and south-east of the United Kingdom.

The North Atlantic is occupied by a persistent area of low pressure in which cyclones are constantly being formed; these beat up against the high European pressure, and either die out or are repelled.

Sometimes, especially in summer, small cyclones, arising on the easterly side of the area of depression, pass rapidly near the British coasts in a north or north-east direction. In either case it is somewhat rare for the center of a cyclone to reach over these islands, so that generally Great Britain is under the influence of the rim or edge of either a cyclone or anticyclone.

At other times the Atlantic low press-

ure extends over Great Britain, driving the high pressure eastwards, without forming any definite cyclone. In this case the indications are for tolerably fine weather and little wind, with a very low barometer: a condition which often excites remark.

In winter the cyclones are usually large, but in summer the general depression of the Atlantic is much less pronounced, while the cyclones are smaller, their centers progress further eastward, and the gradients are less steep. The weather in them is not so dirty, though the air is always close, and the sky is harder than in winter.

This type of weather occurs at all seasons of the year, but is most common and persistent in winter; in fact, the warmth or otherwise of the winter principally depends on the number of days of this type.

The temperature of this type is always high, partly because of the prevailing southerly winds, and when the cyclones die out, the slight degree of cold which follows is very noticeable. Sometimes a portion of the Russian anticyclone reaches Great Britain, and in winter gives rise to white frost of short duration.

The wind in this type is remarkable for its steadiness and absence of gustiness, except when the intensity is extreme; and, for various reasons, the gales of wind do comparatively little destruction either on sea or land, considering their force and duration.

To a single observer the sequence of weather in this type is very simple. As atmospheric pressure falls, temperature rises, and the sky grows dirtier, till drizzling rain sets in. The wind from some point of south, having backed slightly, rises in velocity till the barometer has reached its lowest point; as soon as pressure begins to increase, the wind veers a little towards south-west and gradually falls, the air becomes cooler, and the sky begins to clear; but it rarely becomes hard, or contains firm cumulus. By next day, perhaps, the same sequence is repeated, varying only in intensity, but not in general character, and this alternation often lasts for weeks at a time.

WESTERLY TYPE.

In this type the tropical belt of anticyclones is constantly to the south of Great Britain, and the pressure to the east, west, and especially the north, comparatively low. Under these circumstances, cyclones are developed on the north side of the Atlantic anticyclone, which roll quickly eastwards along the high-pressure belt, usually dying out after they have been detached from the Atlantic anticyclone in their eastward course. Their intensity, and consequently the weather they produce, may vary almost indefinitely.

When the cyclones are formed very far south, so that their centers cross Great Britain, and are of moderate size, the intensity is usually great, and severe well-defined storms with sharp shifts of wind are experienced. These occur most frequently in spring and autumn, and are the most destructive storms which occur in Great Britain.

Another intense form is found in a series of small, short-lived, quick-moving cyclones, and numerous secondaries, without very steep gradients, during which the indications are for rainy broken weather, rather than for storms. This phase is common at all seasons of the year.

In another modification, while the pressure is low to the north, and the isobars run nearly due east and west, the whole of the Arctic area of low pressure surges southward with an exceedingly ill-defined cyclone, bringing a rim of steep gradients along the edge of the Atlantic anticyclone, and across Great Britain, in a manner analogous to a phase of southerly type, before explained. The indications then are for rain, and westerly gales with very little shift of wind. This phase belongs almost exclusively to the winter months.

But the commonest modification at every season, and that which forms about 70 per cent. of our weather, is when the intensity is moderate, and the cyclone paths are so far to the north of the British Islands, that the wind merely backs a point or two from south-west as the cyclone approaches, and veers a point or two towards the west as the cyclone passes, the general direction of the wind being between south-west and west, without rising to the strength of a gale, while rain is moderate in quantity.

To a single observer the principal peculiarity of this type lies in the variable wind and weather. In the southerly type an observer only gets, as it were, the

front of a series of cyclones, while in this type he gets the characteristic weather of both front and rear. In the former condition the worst weather is always in front; while in this the worst often occurs in rear, after the pressure has begun to increase.

NORTHERLY TYPE.

In this type the pressure is high to the west and north-west of Great Britain, while it is low over Germany and Scandinavia, thus giving gradients for northerly winds, from whence the type is named.

Sometimes this high pressure seems to be simply a great extension northwards of the Atlantic anticyclones, on the east side of which cyclones form and pass towards some point of east, thus approximating to a phase of westerly type into which it may merge insensibly. This form is most common in July and August.

More frequently a moderate extension northwards of the Atlantic anticyclones is met by a persistent anticyclone lying over Greenland. On one side any cyclones coming from the American continent are arrested by the belt of high pressure thus formed. On the other side, a large area of low pressure lies over northern and central Europe, which is the theater of the formation of an incessant series of cyclones.

The centers of these cyclones always lie to the east of Great Britain, but modify our weather by their approach or recession. Thus the northerly type, during which Great Britain is constantly under the influence of the rear of cyclones, may be considered the exact converse of the southerly type, during which it is as constantly under the influence of the front of cyclones. This form of the type is most common in the winter, and especially the spring months, notably in March; while it is very rare during the autumn.

To a single observer the most marked feature is the constancy of the wind in the north, generally veering towards north-east with increasing cloud as the barometer falls, and backing towards north-west with brighter weather as it rises; but there is no approach to such a regular shift as occurs in the westerly type. The appearance of the sky is usually hard, and any rainfall takes the form of showers or squalls, rather than of a drizzle or a steady downpour.

EASTERLY TYPE.

In the commonest form of this type, the Atlantic anticyclone is very small and lies far south, while another anticyclone lies persistently over Scandinavia. On the south side of the Scandinavian anticyclone, a cyclone is usually formed over Central and Southern Europe, which either remains stationary, or else moves very slowly towards the west. On the west and south-west side of the anticyclone, cyclones formed in mid-Atlantic press up against it, and either die out, or are rebuffed.

In a less common form, the edge of the Atlantic anticyclone stretches as far north as Portugal, and cyclones coming in from the Atlantic pass across Great Britain in a south-east direction, through the cold which lies between the Atlantic and Scandinavian regions of high pressure.

This type is much more common than the northerly, and occurs at all seasons of the year. It is most common in October, November, February and May, but very rare in July, August, or September.

Though much less common than the westerly or southerly types, it is so stormy that nearly one-half of the wrecks on the British shores are due to gales of this type. This is, however, partly due to the large number of unseaworthy colliers which trade along our east coasts.

To a single observer the general sequence of weather is, that as the barometer falls the sky gets blacker, the air warmer, and the wind veers towards the south-east; then as the barometer rises the air gets colder and the wind backs towards east or north-east, while the strength of the wind and amount of rain depend on the intensity.

In most cases the shift of wind is small, but we may note that the wind veers for an oncoming cyclone, instead of backing, as in the westerly type. This is because the cyclone centers are always towards some point south of the observer.

This type sometimes persists for two or three weeks on end, but no definite symptons of a change of type can be

given. It often succeeds the northern type, and sometimes the two types alternate with one another. At other times the Scandinavian anticyclone lies so far to the south that this type merges insensibly into the southerly.

CYCLONE PATHS.

As the motion of cyclone centers is always towards some point of east, except in certain cases of the easterly type, as already explained, in an uncertain case we may always assume some eastward drift.

Another very noticeable point about cyclones is the tendency of their centers to follow a coast line rather than to strike inland. Also when they do cross the land, they seem to take by preference the lines of valleys, or at all events, of lowest ground, which seem to be lines of least resistance to cyclone motion. In this country cyclone centers have a tendency to pass up channel, or round the northwest coasts of Ireland and Scotland; and when they cross the country they frequently select the line of the Caledonian Canal, or the line of the Forth and Clyde Canals.

GENERAL REMARKS.

Under this head are given a few reflections on forecasting generally.

In the first place, it is remarked that the meteorological changes are so rapid that they can only be traced by means of electric telegraph, and that the expense is therefore so great that this problem can only be efficiently handled by a Central Government Office.

Then as to the amount of detail which is possible, it is manifest that in many cases of small disturbances the minor features, such as squalls, thunderstorms, &c., are so local, that even if it were possible to define their range accurately, every few square miles of the United Kingdom would require a separate forecast, so that it is only the general character of the weather which can ever be forecast, and that, roughly, the larger the scale of disturbance, the more likely are the forecasts to be successful. These minor features are also usually short lived, so that the more frequently the observations are taken, the more unlikely is a storm to escape detection. In summer time a small storm may sometimes form or die out between the 8 A.M. and 6 P.M. reports.

Then, as to the length of time ahead for which forecasts can be issued. It is obvious that owing to the rapid nature of all meteorological changes forecasts can never be issued very long in advance.

It will also be very apparent that the British forecaster labors under peculiar difficulties from his geographical position. Situated on the most outlying portion of Europe, and in the very track of storms which almost always advance from the westward, he has no intimation of an approaching cyclone, till it is actually on him. In the United States and in Germany they are more fortunate. For instance Hamburg often receives timely warning from our English office. In the year 1869, 23 storms were felt in Hamburg, and of these 22 had previously passed over some part of the United Kingdom.

Owing to the nature of weather changes, the average or mean value of any meteorological quantity affords no clue towards estimating the probable change in any existing system. In fact meteorology is not an exact, but an observational science like geology or medicine; and just as however accurately the symptoms or treatment of any malady may be described, the skill to recognize and the judgment to treat must rest on the ability of the physician, so in meteorology, however carefully the relation of weather to isobars may be defined, and the nature of their changes described, the judgment, which experience alone can give, to enable a warning to be issued, must ever depend on the professional skill of the forecaster.

THE mean daily motion of the air in 1884, as given in the report of the Astronomer Royal, was 286 miles, being three miles greater than the average of the last seventeen years. The greatest daily motion was 891 miles on January 23d, and the least, 78 miles on February 8th. The only recorded pressure exceeding 20 lbs. on the square foot in 1884 was 22.7 lbs. on January 23d, after which the connecting chain of the pressure plate broke. It is probable that greater pressures occurred afterwards on the same day, and also in the gale of January 26th, at which date the chain had not been renewed.

THE ELEMENTARY PRINCIPLES OF THE GAS ENGINE.

By DENNY LANE.

From the "English Mechanic."

Before the invention of the steam engine, the only powers employed in mechanics were those of wind and water mills and animal power. In the first two no conversion of one force into another took place; they were mere kinematic devices for employing the mechanical force already existing in the gale of wind and the head of water. With regard to the power developed by man and other animals, we had in them examples of most efficient heat engines, converting into power a large percentage of the fuel burnt in the lungs. But animal power is small in amount, and it is expensive for two reasons—first, because the agents require long intervals of rest, during which they still burn fuel; the next, because the fuel they require is very expensive. A pound of bread, or beef, or oats or beans, costs a great deal more than a pound of coal; while it does not, by its combustion, generate nearly so much heat. The steam engine, therefore, took the place of animal power, and for a long time stood alone; and nearly all the motive power derived from heat is still produced by the mechanism which Watt brought to such great efficiency in so short a time. Now, the practical question for all designers and employers of heat engines is, to determine how the greatest quantity of motive force can be developed from the heat evolved from a given kind of fuel; and coal being the cheapest of all, we will see what are the results obtainable from it by the steam engine. In this we have three efficiencies to consider—those of the furnace, the boiler, and the cylinder. First, with respect to the furnace, the object is to combine the carbon and the hydrogen of the coal with a sufficient quantity of the oxygen of the air to effect complete combustion into carbonic acid and water. In order to do this, we have to use a quantity of air much larger than is theoretically necessary, and also to heat an amount of inert nitrogen five times greater than the necessary oxygen; and we are therefore obliged to create a draught which carries away to the chimney a considerable portion of the heat developed. The combustion, moreover, is never perfect, and some heat is lost by conduction and radiation. The principal loss is by hot gases escaping from the flues to the chimney. Even with well-set boilers, the temperature in the chimney varies from 400° to 600°. Taking the mean of 500°, this would represent a large proportion of the total heat, even if the combustion were perfect; for, as a general rule, the supply of air to a furnace is double that which is theoretically necessary. For our present purpose it will be sufficient to see how much the whole loss is, without dividing it under the several heads of "imperfect combustion," "radiation," and "convection," by the heated gases passing to the chimney.

With a very good boiler and furnace, each pound of coal evaporates 10 lbs. of water from 62°, changing it into steam of 65 lbs. pressure at a temperature of 312°, or 250° above that of the water from which it is generated. Besides these 250°, each pound of steam contains 894 units of latent heat, or 1,144 units in all. A very good condensing engine will work with 2.2 lbs. of coal and 22 lbs. of steam per horse per hour. Now, 1 lb. of good coal will, by its combustion, produce 14,000 heat units, and the 2.2 lbs. of coal multiplied by 14,000 represent 30,800 heat units. Of these we find in the boiler $22 \times 1{,}144$, or 25,168 units, or about $81\frac{1}{2}$ per cent. of the whole heat of combustion; so that the difference (5,632 units, or $18\frac{1}{2}$ per cent.) has been lost by imperfect combustion, radiation, or convection. The water required for condensing this quantity of steam is 550 lbs.; and taking the temperature in the hot well as 102°, 550 lbs. have been raised 40° from 62°. Thus we account for $550 \times 40 = 22{,}000$, or (say) $71\frac{1}{2}$ per cent. still remaining as heat. If we add this $71\frac{1}{2}$ per cent. to $18\frac{1}{2}$, we have 90 per cent., and there remain only 10 per cent. of the heat that

can possibly have been converted into power. But some of this has been lost by radiation from steam pipes, cylinder, &c. Allowing but 1 per cent. for this, we have only 9 per cent. as the efficiency of a really good condensing engine. This estimate agrees very closely with the actual result; for the 2.2 lbs. of coal would develop 30,800 heat units; and this multiplied by Joule's equivalent amounts to nearly 24 millions of foot-pounds. As 1 horse-power is a little less than 2 million foot-pounds per hour, only one-twelfth, or a little more than 8 per cent., of the total heat is converted; so that, whether we look at the total quantity of heat which we show unconverted, or the total heat converted, we find that each supplements and corroborates the other. If we take the efficiency of the engine alone, without considering the loss caused by the boiler, we find that the 25,168 heat units which entered the boiler should have given 19,429,696 foot-pounds; so that the 2 millions given by the engine represent about 10 per cent. of the heat which has left the boiler. The foregoing figures refer to large stationary or marine engines, with first-rate boilers. When, however, we come to high-pressure engines of the best type, the consumption of coal is twice as much; and for those of any ordinary type it is usual to calculate 1 cubic foot, or 62½ lbs. of water evaporated per horse-power. This would reduce the efficiency to about 6 per cent. for the best and 3 per cent. for ordinary non-condensing engines; and if to this we add the inefficiency of some boilers, it is certain that many small engines do not convert into power more than 2 per cent. of the potential energy contained in the coal.

Before explaining the principle upon which the gas engine and every other hot air engine depends, I shall remind you of a few data with which most of you are already familiar. The volume of every gas increases with the temperature; and this increase was the basis of the air thermometer—the first ever used. It is to be regretted that it was not the foundation of all others, for it is based on a physical principle universally applicable. Although the volume increases with the temperature, it does not increase in proportion to the degrees of any ordinary scale, but much more slowly. Now, if to each of the terms of an arithmetical series we add the same number, the new series so formed increases or decreases more slowly than the original; and it was discovered that by adding 461 to the degrees of Fahrenheit's scale, the new scale so formed represented exactly the increment of volume caused by increase of temperature. This scale, proposed by Sir W. Thomson in 1848, is called the "scale of absolute temperature;" its zero, called the "absolute zero," is 461° below the zero of Fahrenheit, or 493° below the freezing point of water; and the degree of heat measured by it is termed the "absolute temperature" It is often convenient to refer to 39° Fahr. (which happens to be the point at which water attains its maximum density), as this is the same as 500° absolute, for, counting from this datum level, a volume of air expands exactly 1 per cent. for 5°, and would be doubled at 1000° absolute, or 439° Fahr.

Whenever any body is compressed, its specific heat is diminished, and the surplus portion is, as it were, pushed out of the body, appearing as sensible heat; and whenever any body is expanded its specific heat is increased, and the additional quantity of heat requisite is, as it were, sucked in from surrounding bodies, so producing cold. This action may be compared to that of a wet sponge from which, when compressed, a portion of the water is forced out, and when the sponge is allowed to expand the water is drawn back. This effect is manifested by the increase of temperature in air-compressing machines, and the cold produced by allowing or forcing air to expand in air-cooling machines. At 39° Fahr. 1 lb. of air measures 12½ cubic feet. Let us suppose that 1 lb. of air at 39° Fahr. = 500° absolute, is contained in a non-conducting cylinder of 1 ft. area and 12½ ft. deep under a counter-poised piston. The pressure of the atmosphere on the piston = 144 square inches × 14.7 lbs., or 2,116 lbs. If the air be now heated up to 539° Fahr. = 1000° absolute, and at the same time the piston is not allowed to move, the pressure is doubled; and when the piston is released it would rise 12½ ft. provided that the temperature remained constant, and the indicator would describe a hyperbolic curve, called an "isothermal," because the temperature would

have remained equal throughout. But, in fact, the temperature is lowered, because expansion has taken place, and the indicator curve which would then be described is called an "adiabatic curve," which is more inclined to the horizontal lines when the volumes are represented by horizontal and the pressures by vertical co-ordinates. In this case it is supposed that there is no conduction or transmission (diabasis) of heat through the sides of the containing vessel. If, however, an *additional* quantity of heat be communicated to the air, so as to maintain the temperature at 1000° absolute, the piston will rise until it is 12½ ft. above its original position, and the indicator will describe an isothermal curve. Now mark the difference. When the piston was fixed, only a heating effect resulted; but when the piston moved up 12½ ft., not only a heating, but a mechanical—in fact, a thermo-dynamo—effect was produced, for the weight of the atmosphere (2,116 lbs.) was lifted 12½ ft. =26,450 foot-pounds.

The specific heat of air at constant pressure has been proved by the experiments of Regnault to be 0.2378, or something less than one-fourth of that of water—a result arrived at by Rankine from totally different data. In the case we have taken there have been expended 500×0.2378, or (say) 118.9 heat units to produce 26,450 foot-pounds. Each unit has, therefore, produced $\frac{26,450}{118.9} = 222\ 5$ foot-pounds, instead of 772 foot-pounds, which would have been rendered if every unit had been converted into power. We therefore conclude that $\frac{222.5}{772} = 29$ per cent. of the total heat has been converted. The residue, or 71 per cent., remains unchanged as heat, and may be partly saved by a regenerator, or applied to other purposes for which a moderate heat is required.

The quantity of heat necessary to raise the heat of air at a constant volume is only 71 per cent. of that required to raise to the same temperature the same weight of air under constant pressure. This is exactly the result at which Laplace arrived from observations on the velocity of sound, and may be stated thus:—

	Specific Heat.	Foot Per lbs.	Cent.
K_p = 1 lb. of air at constant pressure	0.2378 × 772	= 183.5	= 100
K_v = 1 lb. of air at constant volume	0.1688 × 772	= 130.3	= 71
Difference being heat converted into power.	0.0690 × 772	= 53.2	= 29

Or, in a hot-air engine without regeneration, the maximum effect of 1 lb. of air heated 1° Fahr. would be 53.2 f. p. The quantity of heat K_v necessary to heat air under constant volume is to K_p, or that necessary to heat it under constant pressure, as 71: 100, or as 1: 1.408, or very nearly as 1: $\sqrt{2}$—a result which was arrived at by Masson, from theoretical considerations. The 71 per cent. escaping as heat may be utilized in place of other fuel, and with the first hot-air engine I ever saw it was employed for drying blocks of wood. In the same way, the unconverted heat of the exhaust steam from a high-pressure engine, or the heated gases and water passing away from a gas engine may be employed.

When I first wrote on this subject I relied upon some data which led me to suppose that the heating power of ordinary coal gas was higher than it really is. At our last meeting, Mr. Hartley proved, by experiments with his calorimeter, that gas of 16 or 17 candles gave only about 630 units of heat per cubic foot. Now, if all this heat could be converted into power, it would yield 630×772, or 486,360 f. p., and it would require only $\left(\frac{1,980,000}{486,360}\right) = 4.07$ cubic feet to produce 1 indicated horse-power. Some recent tests have shown that, with gas of similar heating power, 18 cubic feet have given 1 indicated horse-power, and therefore $\frac{4.07}{18} = 22.6$ of the whole heat has been converted—a truly wonderful proportion when compared with steam engines of a similar power, showing only an efficiency of 2 to 4 per cent.

The first gas engine which came into practical use was Lenoir's, invented about 1866, in which the mixture of gas and air drawn in for part of the stroke at atmospheric pressure was inflamed by the spark from an induction coil. This required a couple of cells of a strong Bun-

sen battery, was apt to miss fire, and used about 90 cubic feet per horse-power. This was succeeded by Hugon's engine, in which the ignition was caused by a small gas-flame, and the consumption was reduced to 80 cubic feet. In 1864 Otto's atmospheric engine was invented, in which a heavily-loaded piston was forced upwards by an explosion of gas and air drawn in at atmospheric pressure. In its upward stroke the piston was free to move; but in its downward stroke it was connected with a ratchet, and the partial vacuum formed after the explosion beneath the piston, together with its own weight in falling, operated through a rack, and caused rotation of the fly-wheel. This engine (which, in an improved form, uses only 20 cubic feet of gas) is still largely employed, some 1,600 having been constructed. The great objection to it was the noise it produced, and the wear and tear of the ratchet and rack arrangements. In 1876 the Otto-Crossley silent engine was introduced. As you are aware, it is a single-acting engine, in which the gas and air are drawn in by the first outward and compressed by the first inward stroke. The compressed mixture is then ignited, and, being expanded by heat, drives the piston outwards by the second outward stroke. Near the end of this stroke the exhaust-valve is opened, the products of combustion partly escape, and are partly driven out by the second inward stroke. I say partly, for a considerable clearance space, equal to 0.38 per cent. of the whole cylinder volume, remains unexhausted at the inner end of the cylinder. When working to full power, only one stroke out of every four is effective; but this engine works with only 18 to 22 cubic feet of gas per horse-power. Up to the present time I am informed that about 18,000 of these engines have been manufactured. Several other compression engines have been introduced, of which the best known is Mr. Dugald Clerk's, using about 20 ft. of Glasgow cannel gas. It gives one effective stroke for every revolution; the mixture being compressed in a separate air-pump. But this arrangement leads to additional friction; and the power measured by the brake is a smaller percentage of the indicated horse-power than in the Otto-Crossley engine. A number of gas engines—such as Bischop's (much used for very small powers), Robson's (at present undergoing transformation in the able hands of Messrs. Tangye), Korting's, and others—are in use; but, so far as I can learn, all require a larger quantity of gas than those previously referred to.

I have all along spoken of efficiency as a percentage of the total quantity of heat evolved by the fuel; and this is, in the eyes of a manufacturer, the essential question. Other things being equal, that engine is the most economical which requires the smallest quantity of coal or of gas. But men of science often employ the term efficiency in another sense, which I will explain. If I wind a clock, I have spent a certain amount of energy lifting the weight. This is called "energy of position;" and it is returned, by the fall of the weight, to its original level. In the same way if I heat air or water I communicate to it energy of heat, which remains potential as long as the temperature does not fall, but which can be spent again by a decrease of temperature. In every heat engine, therefore, there must be a fall from a higher to a lower temperature, otherwise no work could be done. If the water in the condenser of a steam engine were as hot as that in the boiler, there would be equal pressure on both sides of the piston, and consequently the engine would remain at rest. Now, the greater the fall, the greater the power developed; for a smaller proportion of the heat remains as heat. If we call the higher temperature T and the lower T′ on the absolute scale, T−T′ is the difference; and the ratio of this to the higher temperature is called the "efficiency." This is the foundation of the formula we meet so often: $E=\frac{T-T'}{T}$ A perfect heat engine would, therefore, be one in which the temperature of the absolute zero would be attained, for $\frac{T-O}{T}=1$ per cent. This low temperature, however, has never been reached; and in all practical cases we are confined within much narrower limits. Taking the case of the condensing engine, the limits were 312° to 102°, or 773° and 563° absolute, respectively. The equation then becomes $\frac{773-563}{773}=\frac{210}{773}$ or (say) 27 per

cent. With non-condensing engines the temperatures may be taken at 312° and 212°, or 773° and 673° absolute, respectively. The equation then becomes $\frac{773-673}{773} = \frac{100}{773^\circ}$ or nearly 13 per cent. The practical efficiencies are not nearly this; but they are in about the same ratio, $\frac{27}{13}$ and if we multiply the theoretical efficiencies by 0.37, we get the practical efficiencies, say 10 per cent. and 5 per cent., and it is in the former sense that M. Witz calculated the efficiency of the steam engine at 35 per cent.—a statement which, I own, puzzled me a little when I first met it. These efficiencies do not take any account of loss of heat before the boiler. In the case of the gas engine the question is much more complicated on account of the large clearance space, and the early opening of the exhaust. The highest temperature has been calculated by the American observers at 3443° absolute, and the observed temperatures of the exhaust gases were 1220°. The fraction then becomes $\frac{3443-1229}{3443} = 64$ per cent. If we multiply this by 0.37, as we did in the case of the steam engine, we get 23.7 per cent., or approximately the same as that arrived at by direct experience. Indeed, if the consumption is, as stated sometimes, less than 18 ft., the two percentages would be exactly the same. I do not put this forward as scientifically true; but the coincidence is at least striking.

I have spoken of the illuminating power of the gas as of importance; for the richer gases have also more calorific power, and an engine would, of course, require a smaller quantity of them. The heat-giving power does not, however, vary as the illuminating power, but at a much slower rate; and, adopting the same contrivance as that on which the absolute scale of temperature is formed, I would suggest a formula of the following type: $H=C(I+K)$, in which H represents the number of heat units given out by the combustion of one cubic foot of gas, I is the illuminating power in candles, and C and K two constants to be determined by experiment. If we take the value for motive power of the different qualities of gas as given in Mr. Charles Hunt's interesting paper in our *Transactions* for 1882, C might, without any great error, be taken as 22 and K as 7.5. With Pintsch's oil gas, however, as compared with coal gas, this formula does not hold, and C should be taken much lower and K much higher than the figures given above; that is to say, the heating power increases in a slower progression. The data available, however, are few; but I trust Mr. Hartley will on this, as he has done on so many other scientific subjects, come to our aid.

I will now refer to the valuable experiments of Messrs. Brooks and Steward, which were most carefully made. Everything was measured—the gas by a 60-light and the air by a 300-light meter; the indicated horse-power, by a steam engine indicator; the useful work, by a Prony Brake; the temperature of the water, by a standard thermometer; and that of the escaping gases by a pyrometer. The gas itself was analyzed, and its heating power calculated from its composition as 617.50. Its specific gravity was 0.464, and the volume of air was about seven times that of the gas used (or one-eighth of the mixture), and was only $11\frac{1}{2}$ per cent. by weight more than was needed for perfect combustion. The results arrived at were as follows:—

Converted into indicated horse-power, including friction, &c.	17.0
Escaped with the exhaust gas	15.5
Do. in radiation	15.5
Communicated to water in the jacket	52.0

It will thus be seen that more than half of the heat is communicated to the water in the jacket. Now, this is the opposite of the steam engine, where the jacket is used to transmit the heat *to* the cylinder, and not *from* it. This cooling is rendered necessary, because without it the oil would be carbonized, and lubrication of the cylinder rendered impossible. Indeed, a similar difficulty has occurred with all hot-air engines, and is, I think, the reason they have not been more generally adopted. I felt this so strongly that, for some time after the introduction of the gas engine, I was very cautious in recommending those who consulted me to adopt it. I was afraid that the wear and tear would be excessive. I have, however, for some time past been thoroughly satisfied that this fear was needless, as I am satisfied that a well-made

gas engine is as durable as a steam engine, and the parts subject to wear can be replaced at a moderate cost. We have no boiler, no feed-pump, no stuffing boxes to attend to—no water gauges, pressure gauges, safety valve, or throttle valve to look after. The governor is of a very simple construction, and the slide valve may be removed and replaced in a few minutes. An occasional cleaning out of the cylinder at considerable intervals is all the supervision that the engine requires.

The very large percentage of heat absorbed by the water-jacket should point out to the ingenuity of inventors the first problem to be attacked—viz., how to save this heat without wasting the lubricant or making it inoperative; and in the solution of this problem I look for the most important improvement to be expected in the engine. The most obvious contrivance would be some sort of intercepting shield, which would save the walls of the cylinder and the rings of the piston from the heat of the ignited gases. I have just learned that something of the kind is under trial. Another solution may possibly be found in the employment of a fluid piston; but here we are placed in a dilemma between the liquids that are decomposed and the metals that are oxidized at high temperatures. Next, the loss by radiation—15 per cent.—seems large; but this is to be attributed to the fact that the inside surface of the cylinder is at each inward stroke exposed to the atmosphere—an influence which contributes to the cooling necessary for lubrication. The remaining 15 per cent., which is carried away by the exhaust, is small, compared with the proportion passing away with the exhaust steam of a high pressure, or the water of a condensing engine. As the water in the jacket can be safely raised to 212° Fahr., the whole of the jacket heat can be utilized where hot water is required for other purposes; and this, with the exhaust gases, has been used for drying and heating purposes.

With such advantages, it may be asked: Why does not the gas engine everywhere supersede the steam engine? My answer is a simple one: The gas we manufacture is a dear fuel compared with coal. Ordinary coal gas measures 30 cubic feet to the pound: 1,000 cubic feet, therefore, weighs 33 lbs.; and taking the price at 2s. 9d. per 1,000 cubic feet, it costs 1d. per lb. The 30 cubic feet at 6,300 give 190,000 all available heat. Although good coal may yield 14,000 units by its combustion, only about 11,000 of these reach the boiler; so that the ratio of the useful heat is $\frac{11}{19}$. The thermal efficiency of the best non-condensing engine to that of the gas engine is in the ration$\frac{4}{22\frac{1}{2}}$. Multiplying together these two ratio, we get $\frac{11}{19} \times \frac{4}{22\frac{1}{2}} = \frac{44}{4.28}$. That is, speaking roughly, 1 lb. of gas gives about ten times as much power as 1 lb. of coal does in a good non-condensing engine. But at 18s. 1d. a ton we get 10 lbs. of coal for 1d.; so that with these figures the cheapness of the coal would just compensate for the efficiency of the gas. As to the waste heat passing away from the engine being utilized, here the gas engine has no advantage; and so far as this is concerned, the gas is about eight times dearer than coal. The prices of gas and coal vary so much in different places, that it is hard to determine in what cases gas or coal will be the dearer fuel, considering this point alone.

But there are other kinds of non-illuminating gases—such as Wilson's, Strong's, and Dowson's—which are now coming into use; and at Messrs. Crossley's works you will have an opportunity of seeing a large engineering factory employing several hundred mechanics, and without a chimney, in which every shaft and tool is driven by gas engines supplied by Dowson's gas, and in which the consumption of coal is only 1.2 lb. per horse-power. The greatest economy ever claimed for the steam engine was a consumption of 1.6 lb., and this with steam of very high pressure, expanded in three cylinders successively. Thus in a quarter of a century the gas engine has beaten in the race the steam engine; although from Watt's first idea of improvement nearly a century and a quarter have elapsed.

As regards the steam engine, it is the opinion of competent authorities that the limits of temperature between which it works are so restricted, and so much of the heat is expended in producing a change of state from liquor to vapor, that little further improvement can be made. With

respect to gas engines, the limits of temperature are much further apart. A change of state is not required, and so, very great improvement may still be looked for; and it is not impossible that some of the younger members of our body may live to see that period foretold by one of the greatest of our civil engineers—that the happy time when boiler explosions will be matters of history—that period, not a millennium removed by a thousand years, but an era deferred perhaps by only half a dozen decades, when the use of the gas engine will be universal, and "a steam engine can be found only in a cabinet of antiquities."

ON THE CHANGES PRODUCED BY MAGNETIZATION IN THE LENGTH OF RODS OF IRON, STEEL AND NICKEL.

By SHELFORD BIDWELL, M.A., LL.B.*

From "Nature."

The earliest systematic experiments on the effects produced by magnetization upon the length of iron and steel bars are those of Joule, an account of which is published in the *Phil. Mag.* of 1847. Joule's experiments have many times been repeated, and his general results confirmed. In particular, Prof. A. M. Mayer carried out a series of very careful observations with apparatus of elaborate construction and great delicacy. The conclusions at which he arrived were in accord with those of Joule, so far as regards iron; in the case of steel there was some apparent discrepancy, which, however, might to a great extent, be accounted for by differences in the quality of the metal used and in the manner of conducting the experiments. In 1882 Prof. Barrett published in *Nature* an account of some experiments which he had made, not only on iron but also on bars of nickel and cobalt, with the view of ascertaining the effect of magnetization upon their length.

The knowledge on the subject up to the present time may be summarized as follows:

(1) Magnetization causes in iron bars an elongation, the amount of which varies up to a certain point as the square of the magnetizing force. When the saturation-point is approached the elongation is less than this law would require. The effect is greater in proportion to the softness of the metal.

(2) When a rod or wire of iron is stretched by a weight, the elongating effect of magnetization is diminished; and if the ratio of weight to the section of the wire exceeds a certain limit, magnetization causes retraction instead of elongation.

(3) Soft steel behaves like iron, but the elongation for a given magnetizing force is smaller (Joule). Hard steel is slightly elongated, both when the magnetizing current is made and when it is interrupted, provided that the strength of the successive currents is gradually increased (Joule). The first application of the magnetizing force causes elongation of a steel bar if it is tempered blue, and retraction if it is tempered yellow: subsequent applications of the *same* external magnetizing force cause temporary retraction, whether the temper of the steel is blue or yellow (Mayer).

(4) The length of a nickel bar is diminished by magnetization, the maximum retraction being twice as great as the maximum elongation of iron (Barrett).

In order that the results of Joule and Mayer might be comparable with those obtained by the author, he made an attempt to estimate the magnetizing forces with which they worked. From data contained in their paper, it was calculated that the strongest magnetizing force used by Joule was about 126 units, while the strongest used by Mayer did not on the highest probable estimate exceed 118 units. In the author's experiments the magnetizing force was carried up to about 312 units. The metal rods, too, were much smaller than any which had been before used for the purpose,

* Paper read before the Royal Society.

ranging in diameter from 1.40 to 6.25 mm. Their length was in every case 100 mm., and the apparatus was capable of measuring with tolerable certainty an elongation or retraction equal to a ten-millionth part of this length.

By using thinner iron rods and greater magnetizing forces than those previously employed, the following curious and interesting fact was established. If the magnetization be carried beyond a certain critical point, the consequent elongation, instead of remaining stationary at a maximum, becomes diminished, the diminution increasing with the magnetizing force. If the force is sufficiently increased, a point is arrived at where the original length of the rod is totally unaffected by magnetization; and if the magnetization be carried still further, the original length of the rod will be reduced. It also appeared that the position of the critical point in steel depended in a very remarkable manner upon the hardness or temper of the metal; considerable light is thus thrown on the apparently anomalous results obtained by Joule and by Mayer. Further experiments disclosed strong reason for believing that the value of the critical magnetizing force in a thin iron rod was greatly reduced by stretching; this would explain the fact that Joule obtained opposite effects with stretched and unstretched wires.

By ascertaining the relative values of the temporary moments induced by gradually increasing external magnetizing forces, an attempt was made to connect the point of maximum elongation with a definite phase of the magnetization of the several rods in which the elongation had been observed.

Though more experiments must be made before it is possible to generalize from them with perfect safety, the results so far obtained by the author indicate the laws given below. The elongations and magnetizations referred to are temporary only; before the beginning of an experiment the rod was permanently magnetized by passing through the magnetizing coil a current equal to the strongest subsequently used. In iron the greatest elongation due to permanent magnetization was generally found to be about one-third of the total elongation, while in nickel the permanent retraction amounted only to about one-twenty-fifth part of the whole.

I. IRON.

(1) The length of an iron rod is increased by magnetization up to a certain critical value of the magnetizing force, when a maximum elongation is reached.

(2) If the critical value of the magnetizing force is exceeded, the elongation is diminished until with a sufficiently powerful magnetizing force the original length of the rod is unaffected, and, if the force is still further increased, the rod undergoes retraction. Shortly after the critical point is passed, the elongation diminishes in proportion as the magnetizing force increases. The greatest actual retraction hitherto observed was equal to about half the maximum elongation, but there was no indication of a limit, and a stronger magnetizing force would have produced further retraction.

(3) The value of the external magnetizing force corresponding to maximum elongation is for a given rod approximately equal to twice its value at the "turning point."

Definition.—The turning point in the magnetization of an iron bar is reached when the temporary moment begins to increase less rapidly than the external magnetizing force.

(4) The external force corresponding to the point of maximum elongation increases (when the quality of the iron is the same) with the diameter of the rod. So also does its value at the turning point.

(5) The amount of the maximum elongation appears to vary inversely as the square root of the diameter of the rod, when the quality of the iron is the same.

(6) The turning point, and therefore presumably the point of maximum elongation, occurs with a smaller magnetizing force when the rod is stretched than when it is unstretched.

II. STEEL.

(7) In soft steel magnetization produces elongation, which, as in the case of iron, increases up to a certain value of the magnetizing force, and afterwards diminishes. The maximum elongation is less than in iron, and the rate of diminution after the maximum is passed is also less.

(8) The critical value of the magnetizing force for a steel rod diminishes with increasing hardness up to a certain point, corresponding to a yellow temper; after which it increases, and with very hard steel becomes very high. There is, therefore, a critical degree of hardness for which the critical magnetizing force is a minimum; in steel of a yellow temper the value of the critical magnetizing force is lower than in steel which is either softer and harder.

(9) In soft steel a strong magnetizing force subsequently diminished may cause a greater temporary elongation than the diminished force is capable of producing if applied in the first place.

(10) A temporary elongation when once produced in soft steel may be maintained by a magnetizing force which is itself too small to originate any perceptible elongation.

III. NICKEL.

(11) Nickel continues to retract with magnetizing forces far exceeding those which produce the maximum elongation of iron. The greatest observed retraction of nickel is more than three times the maximum observed elongation of iron, and the limit has not yet been reached.

(12) A nickel wire stretched by a weight undergoes retraction when magnetized.

ELECTRIC TRAMCARS.*

By A. RECKENZAUN.

From "Iron."

It may be premature to read a paper on the subject of electric tramcars, considering that at this moment there is only one such car in existence in this country, so far as the author is aware. This solitary example has, moreover, only been in operation experimentally since October last. It was with considerable hesitation, therefore, that this paper was prepared at the invitation of the council of this institute. The Inventors' Institute has, nevertheless, the privilege before other societies in this respect, that it will judge of the merits of an invention as an invention, apart from the commercial aspect of the problem. Utility, however, is the first desideratum in an invention, and the author now merely submits to this institute the bare question of utility. Before going into the details of our subject, it may be interesting to dwell for a moment upon the figures in the table below, which was prepared in order to show what power a pair of horses are capable of exerting. The power exerted in propelling a 46-passenger car, tractive force 30 lbs. per ton, two horses pulling 4.5 tons, is at—

						Horse-power
7	miles per hour on level road					2.52
6	,,	,,	,,	,,		2.16
6	,,	,,	on a gradient of 1 in 75			4.32
5	,,	,,	,,	,,	1 ,, 37	5.4
4	,,	,,	,,	,,	1 ,, 37	4.32
3	,,	,,	,,	,,	1 ,, 25	4.32
4	,,	,,	,,	,,	1 ,, 25	5.76
5	,,	,,	,,	,,	1 ,, 25	7.2
3	,,	,,	,,	,,	1 ,, 18	5.4

The additional power necessary to pull a car round curves cannot be ascertained with equal accuracy; it depends upon the radius of the curve, the amount of play in the axle boxes, and the size of the wheel flanges; a flexible wheel base will considerably facilitate the movement on curved roads.

STARTING FORCE.

The force required to start a car and to get up speed is necessarily greater than that required to maintain the speed uniformly. "It is a variable quantity," says Mr. D. K. Clark, in his admirable book on tramways, "for it may be anything that horses choose to exert." But it has been found by experiment that the momentary starting force is about four times the tractive force when once in motion; thus we may form a rough idea as to the exertion of a horse in starting

* Paper read before the Inventors' Institute.

a car on the level or on an incline. Horses cannot tell us of their sufferings; we know, nevertheless, that their life in the tramway service is but short, although they work no longer than three to four hours a day. It is barbarous to use horses, as these figures show, yet there has been until recently no economical substitute, and it is only within the last few years that mechanical traction has made any headway. That mechanical power will supersede animal power, and that at no distant date, is admitted on all hands, but the question of the kind of mechanical power to be employed is still an open one. It is often asked why so much mechanical power is required for the propulsion of tramcars, and why it is that a tram locomotive should be made to give as much as 40 indicated horse-power and more, whilst two horses seem to do the same amount of work.

The above table shows what mechanical work is actually being done. James Watt ascertained experimentally that a strong dray horse is capable of producing a continuous effect of 33,000 foot-pounds per minute; but we see that one tram-horse does the work of three or four dray horses very frequently. When we consider that a tramway steam-locomotive often weighs from 8 to 10 tons without the car and passengers, it becomes evident that the indicated horse-power above given is no extravagant measure. Take a locomotive, car, and passengers as weighing together 13 or 14 tons, then, in order to move that load on a level road at a speed of 7 miles per hour, with a tractive force of 30 lbs. per ton, we require from 7 to 8 actual horse-power, which is equivalent, after allowing for engine friction, to about 11 indicated horse-power; and, when traveling up an incline of 1 in 37, something like 34 indicated horse-power. Reducing our figures to a co-efficient, and maintaining that the tractive force is 30 lbs. per ton on a level but dirty road, we come to the conclusion that, when moving at a rate of 7 miles per hour in a straight line, we shall consume 8 foot-pounds of work for every pound of weight on the rails; on an incline of 1.75 we consume 16 foot-pounds, and on an incline of 1.37, 24 foot-pounds for every pound weight carried at the same speed. Therefore it is of the utmost importance to reduce the deadweight to be propelled to a minimum. Where the locomotive engine has to drag the car behind it, it becomes necessary to provide weight in order to obtain good adhesion on the rails, and the best plan, no doubt, would be to utilize the weight of the car and passengers for this purpose.

The number of steam-locomotives employed on tramways is daily increasing, and steam traction is gaining in public favor. It is not, however, within the range of this paper to examine into the advantages or disadvantages of steam traction; but merely to show whether electric tramcars have any chance of success from a utilitarian point of view. We distinguish between the terms electric cars and electric tramway or railway; the electric car carries its energy within itself, and is quite independent of external influences; whereas, in electric tramways, the energy, electricity, is conveyed from the generating station to the rails or other conductor communicating with the motor which turns the car wheels. Separate conductors are used by Messrs. Siemens, at Portrush or elsewhere; Mr. Magnus Volk, at Brighton, conveys the current through the rails—the nature of the ground (shingle) on Brighton beach does not allow of any accumulation of rain or dirt, the rails are above ground, and there is no traffic across the line; an electric tramway is being constructed at Blackpool, where current is conveyed through conductors in a pipe laid underground between the rails; this pipe has a slot throughout the whole length to permit of the connection between the car motor and the conductor beneath the surface of the road. Our electric car, as the model shows, requires no conducting medium; it does not interfere with the rails or roadway nor with other traffic, and it can be shifted from one line to another of the same gauge, it can be run in conjunction with the ordinary horse-cars.

THE BATTERY.

In order to make an electric car, we require a battery which can be stowed away within the car. Such battery has to be of small weight, must be reliable, supply any quantity of current according to the exigencies of the road, must be cheaper than horse flesh, and emit no smell. Primary batteries are out of the question;

the cost of zinc consumed in them would be much greater than that of animal power, independent of the difficulties attending the process of refilling such batteries when exhausted. The invention of the secondary (storage) battery put the question entirely in a new light; certain successful laboratory experiments at once suggested the adaptability of this invention to the propulsion of vehicles. Four years have elapsed since the introduction of the Faure accumulator into this country. It caused quite a sensation at that time, and money could be found in abundance for the exploitation of anything that bore an electrical name. Things have changed entirely since then. The original Faure battery has never been of any practical use, and very substantial improvements had to be made, at enormous expense, to bring the secondary battery to a commercial value. The Electrical Power Storage Company have required the patent rights of M. Faure, in addition to those of Messrs. Sellon, Swan and Volckmar, and they have, step by step, improved the mechanical details of these storage batteries, until they arrived, after immense labor, at what may be termed a thoroughly practical article. But the prejudices created in the public mind by early failures have not quite worn off yet, and it will require something wonderful and startling to convince the public that the work of the last four years has produced remarkable and practical improvements.

None but those who have been intimately connected with the manufacture of storage batteries can form an adequate idea as to the numerous difficulties which had to be surmounted before a permanent success was attained. The battery was long perfect from a theoretical point of view, but it could not stand the test of time—time was an essential factor; it took many months to test the durability of a set of cells, and it was only by close observation and careful remedying of defects, one by one as they appeared, that the storage battery assumed its present form—simple as they may appear to the uninitiated. The cell before you is one of a set of the type specially designed for tramcar work. In a lead-lined strong teak box are placed twenty-one lead plates, weighing together 26 lbs. inclusive of connecting strips and terminals. Ten of these are called positive, and eleven negative. Each plate is formed of a leaden grid, the perforations of which are filled with a paste of lead oxide; the positive plates contain red lead, which, in charging, is converted into peroxide; the negative grids are filled with a paste of litharge, which, in charging, is reduced to spongy lead capable of absorbing hydrogen. We store, therefore, not electricity, but oxygen and hydrogen, which gases, when the battery is discharging, manifest themselves externally in the form of electrical energy. The box is filled with sulphuric acid and water of a specific gravity of about 1150°; then a lid is put on, sealed all round the edges to prevent any spilling of the acid. This acid is never removed so long as the battery lasts. There is no reduction of lead or any material going on within the cell, and the battery would last for ever, but for the fact that the lead grid of the positive plates becomes so brittle through oxidations that it crumbles to pieces in course of time; then, these positive plates have to be replaced periodically by new ones; but the old lead is valuable. The life of a positive plate depends entirely upon the amount of work it has done. The plates in the box before you have been at work since September last, and are still in excellent condition—we should say they are still as good as new. They have frequently been discharged at the rate of 100 ampères, whilst the average working current is 46 ampères, they are always charged at the rate of 32 ampères, and their storage capacity is 150 ampère-hours. Sixty such cells will weigh 1¼ ton, and propel a car with forty-six passengers for about two hours over a road with ordinary gradients, curves, and sixty stoppages per hour.

The diagram (which was exhibited by the lecturer) represents such a car, which has been running at Millwall and at Battersea. The accumulators are placed on trays under the seats out of sight. These trays can be drawn out through doors at one end of the car, and replaced in a few minutes. A trolly containing a fresh set on trays and rollers is drawn up to the end of the car. The discharged cells are pulled out all together by means of a small winch, and the newly-charged cells pushed in, when the car is at once ready to proceed on its journey. There are

three sets of accumulators to each car, two sets being charged, while one set is propelling the vehicle, thereby saving time and preventing delay.

THE ELECTRO-MOTOR.

This machine has to convert the electric current into mechanical power. For tramcar propulsion it is absolutely necessary that the motor should have a high efficiency, and, at the same time, be of small dimensions and of light weight. To combine these requirements has been the aim of the author, and he has, at length, produced a machine which has had some rough tests in actual service under the most trying circumstances and conditions. There are two motors driving the car, each capable of working up to nearly 9 horse-power and weighing 420 lbs. Each motor is supported independently upon a small bogie; the whole mechanism is self-contained; and each separate bogie forms a small locomotive engine, upon which the car rests. One axle of each bogie is a driving-axle. Thus we obtain four small driving-wheels, which give the requisite grip upon the rails. Either bogie can be detached from the car in less than one hour, so that in case of repair and inspection the motor can be taken out and replaced without letting the car stand idle for any length of time. The speed of the motors is high, about 1,000 revolutions, when the car is running at seven miles an hour; thus it is necessary to introduce some mechanical reducing gear between the motor-shaft and the driving-axle.

THE GEARING.

The gearing so employed consists of a worm on each motor-shaft and worm-wheels on the driving-axle giving a ratio of about 1.12. This worm-gearing is boxed in, as likewise is the motor, and the wheels run in oil, dirt is thereby excluded, and the lubrication kept perfect. Easy access is obtained to motors and lubricators through doors in the floor of the car.

VARIATION OF SPEED AND POWER.

This is obtained by means of a compound switch, which arranges the motor-circuits so that the machines shall work in series, in parallel or singly; thus the resistance of the circuit being varied, the power and the speed vary accordingly. When a greater range of speed is desirable, the motor-circuits are still further divided by arranging the field magnet wires apart from the armatures. This obviates cumbersome gearing, which would add to the weight and the expense also—increase first cost and maintenance as well. The driver has full command over the motive power; one handle sufficing for all the operations of starting, stopping, and varying the speed or power. There is no useless electrical resistance, and, therefore, no waste of energy, whatever speed the car may be traveling at. The car is provided with these details at both ends, so that the driver has only to remove the handles and two connections when arriving at the journey's end, and then proceeds. It would be an easy matter to vary the speed by decreasing or increasing the number of cells, thereby varying the electromotive force; this method, however, is injurious to the accumulators, because some of the cells would be discharged sooner than the others, and when they are all re-charged in series, some would have to be very much overcharged before the rest could receive their proper share. There would be not only a waste of power occasionally by the evolution of gases for no purpose, but the life of the cells and their efficiency is reduced by this irregular treatment.

THE BRAKE POWER.

At each platform there is the usual vertical shaft and brake-handle. A chain is wound upon this shaft when the handle is turned, and eight brake blocks are simultaneously pressed against the corresponding number of wheels. The car can be stopped almost instantaneously; but beside this there is an electrical brake, so that the motors act as dynamos driven by the momentum of the car or by the car running down an incline; the whole power stored up in the momentum of the car is converted into electricity and the current generated is utilized in magnetizing the brake-blocks, thereby increasing their grip upon the wheel tires. Arrangements are being made to render this electric brake automatic, so that the main circuit will be broken and the brake-circuit with the motors closed automatically when the speed of the car attains a certain maximum.

COST OF MOTIVE POWER.

It has been mentioned that the capacity of the tramcar cells is 150 ampere-hours. We do not exhaust them entirely, but leave a margin of at least 20 per cent. in the cells. A charge of 120 ampere-hours is sufficient to propel the car full of passengers for two hours or about 12 miles over an average road with frequent stoppages. When charging sixty cells at the rate of 32 amperes for four hours, and replacing the accumulators in the car every two hours, we require steam power to the amount of about 15 indicated horse-power per car. Assuming that the car has to run 72 miles a day, and that we are supplying several cars at the same time from one engine, the fuel consumed need not exceed 4 lbs. per indicated horse-power per hour. The charging takes place during 12 hours of the day only. Thus 7 cwt. of coal per car per day will give a consumption of about 10 lbs. of coal per mile. Reckoning the price of coal at 18s. per ton, the fuel per car-mile would cost less than one penny! By working longer hours, we could do with smaller engines, but, of course, with the same consumption of coal per car-mile. The most economical steam tramway locomotives burn from 9 to 11 lbs. of coal per mile, or about the same as quoted for the electric car. There are two reasons for this consumption. Firstly, the steam locomotive weighs four times as much as the accumulators and electric motor and driving gear—therefore, it requires greater power for its own propulsion; secondly, a tramway locomotive boiler and engine cannot be expected to compete with a large stationary engine as regards economy. The loss thus arising from the conversion of steam power into electricity, and the reconversion of electricity into mechanical power is more than compensated by corresponding advantages. There are instances where water power is available within a reasonable distance from the tramway depot, in which cases the additional economy will be manifest.

PRIME COST, MAINTENANCE AND DEPRECIATION.

The steam engines, boilers, dynamos, and shafting, and all needful apparatus for a charging station to supply a dozen electric cars, including spare power, will cost £4,000, and the complete equipment of twelve two-horse cars, inclusive of ample spare gearing, may be estimated at £6,000. The superintendence of machinery at the charging station will cost £1,100 per annum; fuel at 18s. per ton, water, oil, and waste, £1,400; depreciation, at 10 per cent., on engines, boilers, and dynamos, £400; and an estimated depreciation of 35 per cent. on the whole propelling apparatus. This gives a total expenditure of £5,000 per annum, which is equivalent to 3.5d. per car per mile run. You will observe that these figures are thoroughly reasonable and allow of a good margin. We should have almost to annihilate the whole concern at the end of a year in order to bring the working costs to such an amount as is now allowed by some tramway companies for horsing!

SUMMARY.

I have pointed out the chief but yet only a few of the advantages of this system over horse traction, and I will in a few words enumerate them:

(1) Economy in cost of running, which is estimated at about 3½d. per mile, including depreciation.

(2) The appearance is that of the cars now in general use, and these latter can be readily converted.

(3) The wearing parts of the mechanism which drives the wheels are few in number.

(4) The total weight of the motive power mechanism is less than two tons distributed over two small bogies, whereby the load per unit of rail section is rendered even less than in the case of horse cars.

(5) The propelling apparatus is invisible to the passengers, noiseless, clean, and perfectly safe.

(6) One man (not necessarily skilled) is sufficient to drive an electric car.

(7) The car may be illuminated at night by the electric current sufficiently to enable the passengers to read with comfort, while effecting a saving over oil lamps in cost and avoiding their dirtiness. The power required is so small that the cost may be neglected; the 20 candle-power lamps used consuming only three ampere-hours out of the total of about 150 ampere-hours given by the cells.

(8) The maintenance of the permanent way (including paving) is less than with horse cars, where the hoofs are continuously striking in the same tracks. Existing rails will serve for the electric car of this system, and no additional rail or tube or breaking up of the road is necessary, preliminary to its adoption.

(9) The space required for a charging station is much less than that necessary for stables for a corresponding number of horses.

(10) The same plant which charges the storage batteries may be utilized for lighting the depot and other neighboring buildings by running extra hours at trifling further cost, thus yielding additional revenue.

DISCUSSION.

Professor George Forbes, F.R.S.E., gave a short and concise account of the electric railways laid down in various parts of the world within the last few years, and he considered the methods of conveying the electricity through rails or other conductors clumsy and unsatisfactory. In Mr. Reckenzaun's tramcars they had no stationary engine connected with it by a conductor, and this he considered, other things being equal, a very great advantage. After the experiments made by M. Philippart with tramcars propelled by a Faure battery, he was glad to hear Mr. Reckenzaun say that storage batteries had at last been made commercially useful and practical. He now believed the difficulties which had encountered secondary-battery makers in the past had been surmounted, and that the method of constructing them had been so enormously improved, that those who used them were now masters of the situation instead of *vice-versa*. Pointing to the battery exhibited on the table, the speaker said every one was struck with its light weight, which was brought about by its being made of thin plates, thus giving a large surface and a greater current than had ever be found before in a secondary battery. This he considered one of the chief things they had to be thankful for, because this bringing within a small compass sufficient power to last for a few hours had been their stumbling block in the past. He had been informed that it was impossible to overcharge their batteries and that this could be done for months and months, but it is mentioned in this paper that this overcharging is detrimental to their working. The method of varying the speed and power devised by Mr. Reckenzaun is extremely ingenious and simple, avoiding the disadvantages of mechanical arrangements which would necessarily arise with numerous wheels, chains, or the like. As to the efficiency of electrically-propelled cars as compared with other means of locomotion, he thought that, although steam had made great progress of late years in the propulsion of tramcars, it still had very serious drawbacks, among which were that a small portable locomotive was far less economical than a stationary engine, especially as for the former they had to use a superior quality of fuel. Comparing the Scott-Moncrieff compressed-air car with the one then under discussion, Professor Forbes remarked that it seemed to him that the arguments which applied to one applied to the other, and also pointed out that in Mr. Reckenzaun's car they saw for the first time the application of a worm-wheel to reduce the speed of the motor. In conclusion, he said it was satisfactory to hear that Mr. Reckenzaun was using electricity itself as a brake upon his car, because he thought that where electricity was applied as a motive power it ought also to be used as a brake power.

Mr. Traill (Giant's Causeway Electric Tramway) said that electric-tramway engineers had a great battle to fight. They did not want to replace steam, but to aid railways and, at the same time, the outside public. He thought that through electricity underground railways would become things of the past. There was also the system of overhead tramways, such as was used in America, and which the electric motive power was essentially fitted for, as it did away with the noise and dirt. There were four systems of utilizing the electric energy, and there was no doubt that the system carrying its own motive power, self-contained in its own car, had very great advantages indeed over any other system. The different systems were those which had overhead conductors, those which had side conductors, those which had underground conductors, and the system of accumulators. The overhead conductor was suited to very few places; then there was the side conductor, which they had

adopted on the Giant's Causeway Tramways. This system was very economical, and had many advantages, but after all was only applicable in very few places. There was the underground conductor which could be adapted to street tramways. The fourth system, viz., that of accumulators, had many advantages; indeed, it could be used on any line now worked by horses or steam. After repeated failures at the Giant's Causeway, they had at last hit upon a thoroughly reliable plan for getting the electricity from the conductor. This was by means of a steel spring in the form of a carriage spring, two concave steel springs fastened at the top and rubbing along the bottom.

Professor Forbes: "How long do they last?"

Mr. Traill replied that they had some running for nearly a year, and, when new, they only cost 5s. 6d. He was very much pleased with the system of Mr. Reckenzaun, and, having no doubt that it would come into very large use, he wished it every success.

Mr. Bernard Drake was of opinion that electric cars would have to be made smaller than those which had up to now been constructed in accordance with Mr. Reckenzaun's designs. He pointed out that not only would the smaller cars be more tractable in case of accident, but also that the question of stopping the car would not be so serious, as it stood to reason that if there were forty-six passengers on a car instead of twenty-three, the driver would be compelled to stop double the number of times in a given distance, and that the question of starting such a big car as now used was a severe strain. He considered that the arrangement adopted by Mr. Reckenzaun, of coupling the motors in series or parallel, or running a single motor, was both ingenious and practical; but as regards the overcharging of the extra cells, he thought that the question was more one of carrying the deadweights of these extra cells, which Mr. Reckenzaun had so ably explained was of the greatest importance in ascending gradients than the mere destruction of the cells themselves. It was, of course, wasteful to expend your power in the evolution of gas after the cells were full, and would tend somewhat to soften the peroxide which might, therefore, be more liable to drop out when jolted by the car. He maintained, however, that the overcharging was not nearly as detrimental as was generally supposed. Mr. Drake drew attention to the large output per pound of lead obtained from the tramcar pattern of cell, and the general practical nature of the supporting of the plates and connections, and stated that, as managing engineer of the Storage Company, he felt certain that the company was greatly indebted to Mr. Reckenzaun for the developing of the cells in connection with this class of work, inasmuch as numerous questions of detail had been found out by him, and that by these experiments a most valuable advance had been made in this class of accumulator. Referring to air cars, he thought there were very decided advantages in favor of the electric car, not only in weight, but also from the fact that the pressure of air began to fall from the moment the car came into use, for which mechanical arrangements had to be provided, and also the freezing caused by the expansion of air had to be faced, whereas in the electric car the E.M.F. is practically constant throughout the run, also the electric car would hold its charge for weeks together, whereas the air car charge would entirely leak away in a night.

Mr. Traill rose again and stated that his cars in Ireland have successfully traveled over 30,000 miles with 100,000 passengers, and that the electricity generated by water-power a mile distant costs one quarter of steam used on the same tramway. The commutator of the dynamo made twenty-two million revolutions before it required repairing.

Mr. Shoolbred, M.I.C.E., said that he had seen Mr. Reckenzaun's car running on a difficult piece of line at Battersea, and he was struck with the simplicity of the system and the completeness of design in every detail. He thought that Mr. Reckenzaun's plan of varying the power and speed was just as applicable to a tramway having the current supplied through conductors as it is with accumulators.

Admiral Selwyn, in the course of some general remarks, said he hoped the Inventions Exhibition would help the inventor to take his proper place in the country instead of being absorbed by the

manufacturers, which was, after all, only one result of a defective patent law.

Mr. Waugh having spoken in encouraging terms of the prospects of electrical engineering, the chairman called upon Mr. Reckenzaun to reply.

Mr. Reckenzaun, in reply, testified to the great pleasure and instruction he had derived from the observations of Professor Forbes, Mr. Traill, and the other speakers, and that he felt highly encouraged by the remarks of such authorities. He pointed out that the comparisons made by Professor Forbes between compressed-air cars and electric cars do not hold good in all points, although there is a great similarity in principle. Compressed-air cars are much heavier, the weight of the air reservoirs under the car and its engine cannot be less than four or five tons if made to run eight or nine miles with a pressure of 500 lbs. to the square inch; the accumulators, motors, and gearing in the electric car weigh under two tons in order to propel the vehicle with forty-six passengers over a distance of twelve to fourteen miles, and the time occupied in changing the cells at the end of the journey need not occupy more than three minutes. The moving parts in the mechanism of the air car, like those of the steam car, are at least five times in number as compared with the parts on the electric car, and this must be taken as a very great advantage. Moreover, the efficiency of the compressed air engine is lower than that of the accumulator and electric motor. Mr. Drake has very justly said that whilst the pressure in the air car is gradually falling, the current of the electric battery is constant throughout, but as regards Mr. Drake's opinion that small cars may be more efficient than large ones, Mr. Reckenzaun remarked that a car capable of carrying only twenty-three passengers will weigh much more than half the weight of a 46-passenger car, and that if the traffic is sufficiently large, the bigger cars may be more economical. As regards the overcharging of the batteries, if some cells were used more than others of the same series, which would occur were the speed and power regulated by the number of cells, more stress should have been put in the text of the paper upon the fact that the energy wasted is more serious than the fact of sooner oxidizing the lead plates. Still, the object of the present system of regulation removes both these drawbacks.

A COMPARISON OF BRITISH AND METRIC MEASURES FOR ENGINEERING PURPOSES.

By ARTHUR HAMILTON-SMYTHE, B.A., M. Inst. C.E.

Proceedings of the Institution of Civil Engineers.

III.

Professor H. Hennessy observed that the utility of a complete international system of weights and measures, based on the existing international system of counting and calculation, seemed to be clearly established, and the author of the paper had shown that no profession would profit more by such a system than the profession of civil engineering. If the whole question were open to revision, probably a decimal metric system, founded upon a standard of length common to all nations, such as a fraction of the earth's polar axis, would be most acceptable. This had been proposed by Professor Hennessy long since, and a complete series of measures and weights derived from it had been exhibited at South Kensington in 1876. It fulfilled all requirements of a complete system, and on account of the close approach of one of its fractions to the existing British inch,* it was strongly supported by some eminent persons, but when he reflected on the fact that the majority of the civilized part of mankind had already adopted the French metrical system, and that every day this system was becoming more fa-

* The polar inch differed from the British inch by the thousandth part less.—H. H.

miliar to British students of engineering through their observation of foreign works, or perusal of foreign scientific and technical publications, he could not hesitate to express his concurrence in the views of those who advocated its adoption for all nations. Some inconveniences would have to be endured for a short time before workmen and calculators were familiar with the new system, but these inconveniences had been cheerfully encountered by great nations already, and their experience might be fairly appealed to in answer to this difficulty. Men of science and engineers, whose minds were accustomed to accurate estimates of number and magnitude, would, in general, have no difficulty in employing more than one system. Thus, while he had found it advantageous to use the decimal metrical system in applied mechanics, thermodynamics, and mathematical physics, he had been often obliged also to employ the British system, on account of its use in ordinary applications. But this very circumstance had only made the superiority of the metrical system more distinctly felt, and made him more than ever desire that it alone should be employed throughout the world.

Mr. C. L. Hett remarked that in 1870 the Butterley Company obtained the contract for the Dordrecht Railway Bridge, and he had prepared the drawings for the steam cranes, scaffolding, &c., required in its erection. As the piling and superstructure of the staging had to be erected by a Continental contractor, the drawings were made to metric measures. Drawing-scales were ordered with the most generally used English graduations on one edge, and corresponding metric divisions on the other. By the use of these scales all difficulty was overcome, and rapid progress made. The drawings of the bridge itself were prepared in Holland, under the supervision of the Dutch Government engineers, and were dimensioned in metric figures throughout. But in the works there was an outcry. The men at first said they could not and would not work to such outlandish dimensions. The purchase of a few metric rules, however, settled the difficulty, and, after a fortnight's practice, one of the old hands who had been most opposed to them, admitted that the metric measures were much the easiest to use, especially where an even pitch could not be employed, but a given number of equidistant rivets had to occupy a certain space, the pitch being an odd dimension. It should be mentioned that no member of the Butterley staff nor any of the workmen had had any previous experience of metric measures. The absurdity of the present system of measurement was well exemplified in the case of railway bridges and of drainage pumping works. In each case a plan of the site was supplied drawn to a scale of chains and links, the heights being given in feet and decimals of a foot, while the drawings for the ironwork were made in feet and inches. The standing arguments used against the metric measures were the Whitworth screw-threads, the 1-inch and 6-inch ordnance maps, and the loss that would accrue from the depreciation of patterns and templates. The former difficulty was not felt abroad when the metric system was established, any more than inconvenience was experienced at home from the odd diameters of the standard gas-threads. The second objection could be removed by engraving metric scales on the plates from which the maps were printed. At present, owing to the variable contraction of the paper, accurate measurements could only be taken with the scale printed on the maps. Even now the ordnance maps on the larger scales were made without regard to the time-honored yard and inch, being plotted to scales of $\frac{1}{2500}$, $\frac{1}{500}$, &c., of the actual size. On such maps, metrical scales could be used with great convenience, but a rule divided into inches was valueless. The last objection appeared at first to be a very important one, yet it was more so in appearance than in reality. A thoroughly good set of patterns or templates would retain their value, while obsolete ones would probably be destroyed rather sooner than if there had been no change in the measures.

With regard to the British system, or rather want of system, of weights, little need be said. In trying to improve them, matters had only been made worse. The cental of 100 lbs. originated with the Liverpool corn merchants, who after using it illegally for years, obtained Government sanction for its adoption in 1879.

It was expected to effect a reform in the sale of corn, but nothing of the kind had occurred. At present a bill was before the House of Commons to render the use of the cental compulsory in the corn trade of England. The scheme of decimalization of the coinage mentioned by the author, and which had been so frequently advocated, might be easily introduced. The poor would approve of it, as they would get 12½d. for 1s.; but the difficulty would be in the temporary loss to the revenue of 4 per cent. in postage and receipt stamps. Although this subject had been thoroughly discussed years ago, it was under very different conditions to those which now prevailed. At that time there was hardly a competitor with England in the foreign trade. The British were virtually in a position to dictate to countries employing the metric system, and to say, "There is our machinery made to our measurements, and without the slightest consideration of your convenience." But now it was different; there were makers from countries employing the metric system ready to supply any order for machinery, and year by year the excellence of their goods would be improved until their workmanship was equal to our own, and our last advantage over them would be gone. It was sometimes urged that if the United States did not adopt the metric system, why should England? The Americans were agitating for its adoption, and the first country to change would have a great advantage in trading with those other nations who had already adopted it. At the same time America did not purchase machinery from the British, and therefore their case need not be considered. Now that education was compulsory, the extra work involved on the rising generation and their instructors by the clumsy system of English weights and measures should be carefully considered. As so much was being spent in education, and cases of "over-pressure" were so frequently reported, should not an effort be made to abolish a system which was admitted on all hands to involve an enormous amount of unnecessary labor? The feeling that the metric system must sooner or later be adopted was not confined to engineers and scientific men; it was shown by the action of the Leicestershire Chamber of Agriculture in 1878, which opposed the legalization of the cental on the ground that it might impede the adoption of metric weights and measures. Few persons attempted to defend the present system, yet there was a general hopelessness of any change. Improvement had been advocated, but any alteration would involve greater confusion than a total change, while the international character of the metric system would not be attained. The importance of the subject was so great that Government might be expected to aid the change by adopting the metric system throughout their departments. If adopted exclusively in the customs, metric weights would immediately be made the basis of railway charges, much to the relief of goods clerks and accountants. Wholesale houses would follow, and gradually the system would be accepted by the small retailers.

Mr. Ferdinand Hurter, Ph. D., held that the only important reason for a change from the English to the metric system was that many nations had adopted the latter. Perfect internationality was, however, impossible, since Germany had not adopted the coinage of other continental countries. The metric system did not save so much time as was usually claimed for it. Where a decimal system was obligatory, the English people used it. True, it required more time to attain a knowledge of the English system and its special arithmetic at school; but that time was not lost, and the pupil who mastered the greater difficulties became the better man in the end. The examples of saving of time which the author had given were not very well chosen. If the French carpenter had a folding meter rule, he would not measure more quickly than the English carpenter; if the rule were not jointed, give the carpenter a five-foot staff or a measuring tape. The multiplication which the author supposed the carpenter to make was never made to his knowledge. The carpenter said 2, 4, 6, &c., as he turned the rule over. He was certain that a man well acquainted with his business could accomplish as much work, on an average, by the English system as he would by the metric system, and in considering so important a question as a change from one system to another, the

difficulties which the system presented to the uninitiated must not be left out of sight. The calculation of the weight of water in a tank could have been much shortened by abandoning the decimals of feet, and by remembering that one ton of water was 36 cubic feet (error 0.2 per cent., or 5 lbs. to the ton). One point had been overlooked by the author, namely, that the one-foot rule was as often used as an instrument for subdividing as it was to obtain data for a calculation. In this respect the one-foot rule, with its binary and ternary subdivisions, was as much superior to the metric rule as a circle divided into 360° was superior to one divided into 100°. Suppose it was required to subdivide 1 meter, this could be done by means of one thousand divisions in fifteen different ways. Take the same length, 39⅜ inches, and use an English two-foot rule, divided into sixteenths of an inch, and there were twenty-three ways of subdividing it into equal parts, though the eye had only 630 divisions to examine, instead of one thousand. But, compare the yard in this way: it could be divided by means of an English rule, obtainable for 3s., in forty-two different ways. It was in the workshop that the English system was superior to the French; and the English inch was the standard for screw cutting, not only in England, but throughout the world. It must not be forgotten that the British public was not prepared, nor preparing, for such a change. Decimal calculation was unknown to the mass of the people. Boys were allowed to leave school, having passed the fifth standard, void of all knowledge of decimal arithmetic. Surely it would be unfair to take the masses by surprise! But, if the metric system must be, let it be the metric system pure —the metric system compulsory; not a metric system at the option of any engineer. Let there be no mixture, particularly in plans to be submitted to, and discussed by, parliamentary committees.

Mr. L. D'A. Jackson observed, with regard to the choice between British and French metric measures, that British engineers dealt more with persons of their own nation, with colonial English, with citizens of the United States of America, and with semi-civilized and barbarous nations, than they did with nations that had adopted the French metric measures. Hence British measures were preferable for the English engineer. It was also important to notice that Russia used British measures in part. This first guide to choice should certainly settle the matter. Next, the British measures were good, useful, suitable, and convenient measures, while the French metric measures were mostly mere nominal units, among which there were only three or four useful measures. Lastly, there was no excuse for adopting the bad measures of the French in England, where a single, though incongruous system, already existed. When the French, the Italians and the Germans adopted them, they had booksful of various measures of their own, and their internal jealousies prevented them from selecting among the best of those well known. Moreover, the installation of the meter was effected by fine and by imprisonment, the leading men having been previously won over by flattery. Engineers found that the British measures were inconvenient for purposes of calculation. If, then, they wished to decimalize, let them decimalize on their own existing units, thus keeping themselves in accord generally with the measures of their own nation. The selection of British units for decimalization should be left to committees of experts. In the interim, engineers should be allowed, by Act of Parliament, or by Order in Council, to decimalize without restraint on any or all of the existing British measures, with the sole restriction of adherence to some one unit and its decimal multiples, and sub-multiples, in each class of measure. The difficulties would be few, as any one complete decimal system was easily comparable with any other complete decimal system within the separate classes of length, surface, cubic and weight units.

Professor Fleeming Jenkin said he should like to record his opinion that if any change were made by engineers in their standards of measurement, they should adopt the C. G. S. system, as it is called, with absolute derived units for force, &c. This change must, in his opinion, be made sooner or later, whether engineers liked it or not; and any half measure, such as taking a kilogram as a unit of force, or a kilogrammeter as a unit of work, would only entail addition-

al inconvenience; but dynes and ergs had a clear practical advantage to recommend them. The C. G. S. system (centimeter, gramme, second) had been already sanctioned as regarded electrical measurements by the International Conference of 1883 and 1884, held in Paris under the presidency of M. Cochery. This was the thin edge of the wedge, and since the wedge was a good strong one, and the motive for driving it home was of overwhelming importance to physicists, driven home it would be. Those who wished to know what the C. G. S. system was might consult Everett on "Units and Physical Constants." If this system had been in practical use, the labor of preparing, for instance, his lecture on Gas Engines would have been halved, at least.

Mr. S. W. Johnson remarked that for the last twelve years the decimal system of measurement on the Midland Railway, referred to by Mr. Fernie in 1863,* had been employed only for the tire boring, for contraction, and for the purpose of measuring test bars, while Whitworth's templates and gauges were in use for all other workshop details.

Mr. T. J. Nicholls observed that the incongruities and anomalies which were of daily experience under the accepted methods of weighing, measuring, and valuing, might be illustrated by reference to "Portland Cement." The evil was first apparent in the specification, drawn more or less in the following general terms: "The cement shall . . . and weigh . . . pounds per bushel (striked); . . . per cent. must be retained on a sieve of . . . meshes per square inch; and bricks of the neat cement must be equal to a strain of . . . pounds per square inch. The tests will be applied to . . . bricks in each lot of . . . tons," &c. But this did not exhaust the weights and measures connected with cement. It was sold "by" the ton (never by the bushel), and "in" either bags or casks of indefinite, varying bulk and weight. It was commonly used by the cubic yard (concrete), or square yard (plastering, flooring, &c.). The annexed table presented a transaction in Portland cement, in terms which were hardly credible as being those of actual experience: cement was

Specified for density	per bushel.
The full of the bushel to weigh so many	pounds.
Bought "by" the	ton.
Delivered "in"	bags or casks.
Tested for fineness	per cent.
" over so many meshes per inch depending on	S. W. G.
" for strength in lbs. per	square inch.
And used by the	cubic yard or square yard.

Surely the fittest parallel to such application of figures as Portland cement evidently required, was to be found in the old farmer's clock which, to those who knew its ways, told half-past four in the day by striking twelve and pointing to five minutes to nine. A similar juggling had to be performed in dealing with iron. It was generally held to

Weigh	a decimal of a pound per cubic inch	pounds. / per square foot 1 inch thick.
Was measured in		feet and inches.
Priced and brought per		ton.
Tested for tensile strength in pounds per		square inch.
" for elongation decimally		per cent.
" for deflection by a binary sub-division of the		lineal inch, or by per cent. of span.

To give an additional example: Take the apparently simple case of estimating the weight of rails per mile of railway—

Rails, say	80 pounds per yard.
The multiplier for pounds per mile was	1,760!
And the divisor for tons per mile was	2,240!

Compare the arithmetical process involved by these figures with the methods of arriving at the number of units of gross weight under the decimal (metric) system, which was, so to speak, automatic.

Rails, say	40 kilograms per meter.
Both: multiplier for weight (kilog.) pr. mile (kilometer) and divisor for tons (milliers), though little used)	=1,000

Thus the arithmetical process was effected immediately, and the required result obtained by simply changing the names of the multiplicand from kilograms to milliers.

To revert to the units in the case of Portland cement. It would be observed that only "pounds" and "tons," and

* Minutes of Proceedings Inst. C. E., vol. xxii., p. 606.

"square inch" and "square" or "cubic yard" had any fixed relationship, according to any tables in existence; and for purposes of calculation, these relationships were represented by the numerical expressions $\frac{1}{2,240}$, and $\frac{1}{36\times36}=\frac{1}{1,296}$, and $\frac{1}{36\times36\times36}=\frac{1}{46,656}$; while under a decimal (such as the metric) system, the representative fraction would be $\frac{1}{1000}$ or 0.000, and sub-multiples or multiples of it. The bushel was said to be of a capacity which, stated in terms of British units, simply could not be measured. On the authority of "Molesworth" it might be taken as equal to $2,218\frac{16}{100}$ cubic inches $=1\frac{28}{100}$ cubic foot. The inch and the foot (which were too small and too large as units of minimum dimension), were defined, or at least, their sizes were accepted, conventionally. Not so the pound weight. The British "system" boasted two distinct pound weights; and while those who knew what was meant, professed to find things easy, it could not be quite so clear to foreigners who might wish or require to refer to English calculations.

A popular magazine had lately informed its readers that a "grain" of gold might be beaten out to cover 56 square inches, with leaves only $\frac{1}{282000}$ of an inch in thickness. What did the statement convey to the general reader as to the relationship of the "grain" to the "inch," square or lineal? None; There was no such relationship. Casual readers might forget that there was any use for the word "grain" so applied, other than as a rough indication of minute bulk; but ancient history traced connection between it and the grain of wheat as a measure of weight; yet it might be that the "grain" of gold referred to would but ill compare with the grain of wheat, either as to size or weight. Hence the particulars in the statement, though not detracting from the wonderful ductility of gold, were wholly worthless as a comparison of actual facts. Anyone having more or less intimate knowledge of workshop practice, or intercourse with the foremen of departments, would realize the contortions of memory and the evolutionary processes necessary to enable the mind to comprehend the rough cube of a piece of stick which was announced to be 2 feet $1\frac{3}{4}$ inch long, $4\frac{5}{8}$ inches broad, and $\frac{7}{8}$ and $\frac{1}{16}$ inch thick. Such an experience might be compared with the equally systematic measurement of a timber log by a farm hand: "Five times the length of my stick, twice the length of my foot, then this straw, then half a brick, and a bit over." He had heard a university fellow and professor boast to his pupils that he had never mastered and did not "know" the English tables of weights and measures. The professor always had his sympathy.

It was to be hoped that the paper would lead to useful results. The advantages of the alteration it advocated were far from being overrated; they were such as seemed to afford an occasion for the origination of a movement having in view the final substitution of a simple and attractive system of numbers, already well tested, for the present anomalies, and the illogical jumble of terms and quantities. It would not be enough to decimalize the British tables of weights and measures; that was impossible, however practicable to deal in that manner with the coinage. Sooner or later there must be a complete decimal system for all purposes of calculation and measurement. It was to be hoped that it might not remain to be secured for the English, as it had been for the French, among the results of a sanguinary revolution.

Mr. C. E. Parker-Rhodes, late of H. M. Consular Service, was in favor of the metric decimal system in substitution for the present British weights, measures, and coinage. In the adoption thereof for all purposes no difficulty would arise, even in ordinary commercial and trade transactions, particularly in the measurement of land. As to advantages, he need only state that a case of survey had recently been submitted to arbitration at the Surveyors' Institution, in which an error of 1 acre in excess existed where the correct quantity was a little over two acres. Saving of time in calculation was likewise in favor of the system now acknowledged by numerous States; and by the diminution of operations and figures the memory was less taxed. The liability to error was also reduced to a minimum. The conversion of British weights, measures, and currency in foreign countries would always be to the disadvan-

tage of British interests, at the same time resulting in considerable fluctuations. International uniformity was greatly needed, as might be proved by the importations of all commodities under the British flag in foreign countries.

Mr. R. H. Smith thought experience proved that there was no great difficulty in introducing new measures into the practical life of a nation; certainly not as regarded engineering practice. Putting the case of France aside, Germany, Russia, Italy and Austria had adopted the French metric system throughout, practically, the whole of their engineering work, and had become familiar with it within a comparatively short period. Again, Sir Joseph Whitworth's workmen used a system different from any other, namely $\frac{1}{10}$ inch, and this without difficulty or liability to error. In the workshop liability to error was, under existing circumstances, more often due to the workmen having a variety of conflicting scales marked on their rules than to any other cause. The theoretic objection most commonly made to the metric system was that the duodecimal division was more advantageous than the decimal. As a matter of theory, he thought this argument mistaken. There was a real necessity for representing the fraction $\frac{1}{2}$ in the simplest possible fashion, whatever system might be adopted, because of the great physical importance of binary symmetry for the sake of balancing weights, &c. The great majority of dimensions was for such reasons marked off in halves, but beyond the fraction $\frac{1}{2}$ he thought no fraction had any more importance than another. Physically, the dimension of 0.88 inch would suit every purpose just as well as $\frac{7}{8}$ inch. Physically it was just as convenient to buy in 0.765 ton of iron as 15 cwt. If the 0.75 was preferred, it was only because the notation made 0.75 a little more easy to calculate than 0.765. If the notation adopted made it easier to reckon 0.765 than 0.75, then the commonly used fraction would be 0.765 and not 0.75. Therefore, so long as the system of notation represented $\frac{1}{2}$ simply, *i. e.*, so long as its base was an even number, he thought it of little theoretical importance what base was taken. Obviously 2 or 4 was clumsily small, because with these large numbers would be represented by great arrays of figures. Practically it was of the utmost importance to adhere to 10, because, although he believed it would be easy to introduce new physical quantitative units, he knew from repeated attempts that it was extremely difficult to change the fundamental idea of numerical notation, and also because the decimal system was not only deeply ingrained in our minds, but was widespread over the world, there being no nations having any notation at all, who did not count by it. No one who had lived and worked on the Continent, and who recollected at the same time what was the usage of scientific men all over the world, could for a moment contemplate the possibility of converting the continental peoples to the use of British measures. It followed that if an international system of measurement was to be attained, it could only be accomplished by the approximation of British to the best metric system that would be generally acceptable. Men devoted to pure science used now almost exclusively the centimeter and its derivatives. He believed the centimeter was commonly used in France by engineers also. In Germany, however, the millimeter was almost universally employed by engineers as the unit of length. The reason evidently was that the centimeter was too long to make it possible even commonly to avoid fractions in dimensioning drawings, &c. In calculating the diameter of a shaft, for instance, it would be most improper to round off the result to a whole number of centimeters, unless the size were an unusually large one. The thicknesses of plates could never be expressed without fractions. But in practice it was found that a fraction of a millimeter need never be used, except occasionally in fitting dimensions together, or for sheet metal, or for wire. The committee of the British Association recommended the adoption of the centimeter and the gram, because the system so based made the specific gravity coincide with the specific weight (weight per unit volume) of each substance. He submitted that this was no good reason. Specific gravities were of no use to engineers, or any other class of practical men. Tables of specific gravity he had always looked upon as nuisances. Weights should be calculated from experiments on the heaviness of the material dealt with, and from

linear measurements. For this purpose specific weights were wanted, not specific gravities. With tables of specific gravities only to go by, a double multiplication must be made where only one was needed according to any rational method. To realize the excessive uselessness of specific gravities, it should be remembered that the comparison only referred to water at one particular temperature and pressure. It so happened that in the one instance, where it appeared at first sight that specific gravities might be of direct practical use, namely, in the calculation of the buoyancy of ships; the specific gravity of the water to be dealt with, namely sea-water, was so far from unity that the difference could not be neglected. Specific weight was what was always practically dealt with, and the specific weight of water was certainly not the most important specific weight entering into the calculations of engineers. It was hardly used, except in hydraulic engineering. In steam engineering, that of steam was of vastly more importance than that of water. He thought, therefore, that for practical purposes there need be no definite relation between the units of length and of weight or mass, and the most convenient units he had used in his own calculations were the millimeter and kilogram.

Mr. W. E. Thursfield observed that there could be no question as to the desirability of an international standard of weights and measures for engineering purposes; and, as England and America were the only two countries which still retained their old-fashioned and complicated methods of arriving at arithmetical conclusions, nothing more than their common assent was necessary to give an international character to the metric and decimal systems employed by engineers on the Continent. Having had some twenty years' practical experience of the immense saving in time and labor, of the simplicity of manipulation, and of the greater accuracy obtainable by the use of the meter as the standard of all dimensions in every branch of technical work, he had great pleasure in bearing testimony to the undoubted advantages, in the several instances adduced by the author, of the metric and decimal systems, and in supporting his arguments in favor of their adoption in place of any other. With regard to the depreciation of existing English technical literature, and of machinery compiled and constructed in accordance with the present systems of calculation and measurement, the rapid improvements in detail, and the wear and tear of material, necessitated renewal from time to time; and the advantages to be derived by the student, as well as by the manufacturer, from the means afforded them, by an international standard of comparison, of judging the theoretical and practical results of their professional brethren in other countries, must be of more value than the loss of waste paper and of old metal, left on their hands at the end of the period of transition. In drawing a comparison between the descent in integral fractions, of the subdivisions of a meter, and of an inch (as quoted by the author), Mr. Sellers appeared to have lost sight of the fact that the meter was divided into 1,000 parts, not 100; and that it was, consequently, capable of fourteen integral subdivisions—$\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{8}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{25}$, $\frac{1}{40}$, $\frac{1}{50}$, $\frac{1}{100}$, $\frac{1}{125}$, $\frac{1}{250}$, $\frac{1}{500}$, $\frac{1}{1000}$, all of which could be contained on one scale; whereas, to obtain the full benefit of the inch scale, three separate forms of subdivision, or three scales, were necessary, namely, the inch divided in terms of $\frac{1}{8}$, $\frac{1}{10}$, and $\frac{1}{12}$. That sizes of machinery advancing by $\frac{1}{16}$ inch were more useful and salable than those advancing by millimeters, was rather a matter of local prejudice than of universal opinion. It must be immaterial to a purchaser whether the cylinders of several engines submitted for his choice had advancing diameters of $9\frac{7}{16}$ inches, $9\frac{1}{2}$ inches, and $9\frac{9}{16}$ inches, or 239 millimeters, 241 millimeters, and 243 millimeters, as the respective differences between the latter dimensions in millimeters and the former in sixteenths of an inch, were only 0.25, 0.08 and 0.07 per cent. It would be equally correct to surmise that a fourteen-hand cob and a sixteen-hand hunter would be less useful and salable if advertised at 147.5 centimeters and 168.5 centimeters, supposing the purchaser to be intimate with the metric system. If anything, he thought the author undervalued the saving in time by the use of the metric and decimal system in calculation; the surveyor, most expert at quantities, with the handiest of ready reckoners, would

scarcely be able to work out the same number of items expressed in tons, cwts., qrs., and lbs., at x shillings per ton, in one hour, as could be calculated by anyone, with only a short practice in the decimal system, in three-quarters of an hour, if the weights were expressed in kilograms, and price in shillings per meter ton, to say nothing of the increasing chance of error in proportion to the greater number of operations, and of the longer time necessary to check the results, without which the calculations were useless. With regard to the extension of the metric and decimal system to the purposes of general commerce, he agreed with the author that the full benefit of such a step could only be reaped in conjunction with a compulsory system of decimal coinage; but in the face of the competition of over one hundred and eighty millions of European producers, of whom one hundred and twenty millions either held or were hungering after Colonial possession as outlets for their produce, or as standpoints from which to assail the mercantile supremacy of England, all using one standard of measure, differing from, and simpler than, the British; he thought it would be wiser, if also the mercantile world, or so much of it as would have to withstand the attack of foreign competition, were to place itself on an equal footing with its competitors by adopting, as early as possible, their standard of mensuration.

The course of dissemination, before its adoption became compulsory, was sketched by the author in his reference to the method by which the change was effected in Austro-Hungary. He thought, however, his suggestions might have gone further, and that part of the burden laid on engineers might have been transferred to the shoulders of the schoolmaster. It was of no use to familiarize the workmen with a new and simpler system of measurement and calculation, if their children, who, in all human probability, were destined to take their place, were brought up in an old and complicated one. In conclusion, he agreed with the author that practically the decimalization of the coinage was as simple, if not easier, than the conversion of weights and measures for commerce. This had been aptly illustrated in Germany, where one universal standard of monetary value had been introduced in place of the heterogeneous coinages of her numerous petty States; and in Austria, where the florin, formerly composed of 60 kreuzers, now contained 100. Yet, in both countries no other change than that of nomenclature had taken place in measuring many articles of daily use. For instance, the old Krügel (0.531 liter) had become the modern $\frac{1}{2}$ liter; the old Seitel (0.353 liter) $\frac{1}{3}$ liter; the Pfiff (0.177 liter) $\frac{1}{6}$ liter. Meat and other commodities, formerly sold by the pound, were now computed by the $\frac{1}{2}$ kilogram, and so on, with, however, be it remarked, almost invariably a slight loss to the public, and a corresponding advantage to the tradesman.

MECHANICAL INTEGRATORS.

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I.

All measurements are made in terms of some fixed unit. The method may consist of a simple comparison of the unit with the quantity to be measured, but when this cannot conveniently be done, some indirect means must be employed. Indirect measurements may be made by measuring some physical effect, the magnitude of which is known to be a function of the quantity to be measured, as, for instance, when the length of a rod or wire is estimated by its weight. Where, however, the unit, in terms of which the measurement has to be made, is what is known as a derived unit, the indirect method generally consists in measuring in terms of the simple units from which the former is derived, and performing, with the results, the necessary calculation. An example of this latter method

is given in obtaining the contents of an area, by taking its length and breadth and multiplying them together, instead of adopting the tedious process of ascertaining, by direct comparison, how many times the unit of area would be contained within it.

Now, such calculations, even when of so simple a kind as mere multiplication, often become very inconvenient, and a large number of instruments have been designed for performing them by mechanical means. Such instruments may be divided into two classes, one in which the final result of conditions which vary in an arbitrary manner is found, such as the contents of a surface or the work of a motor, requiring a process of multiplication or addition; the other in which the relation or ratio, at any instant, of two such quantities is given, such as space and time in the case of velocity, requiring at each instant a process of division. The object of the present paper is to deal with the theory, design and practical applications to engineering problems of the former class alone. It may be briefly stated that very little has yet been practically done in the use of the latter. Quite recently, Professor A. W. Harlacher, of Prague, has published an account of the instruments and methods of Harlacher, Henneberg and Smreker, for gauging the velocity of a river current, the principle of which is the same as that independently adopted by the author and others in this country.

The conditions or data above referred to, from which the required result has to be calculated by instrumental means, are obtained in two ways:

(1) By intermittent or separate observations and measurements.

(2) By the continuous motion of a machine in connection with self-recording apparatus.

The former is the case in measuring an area of country, taking dimensions of a river or embankment section, or obtaining the forces exerted at different times by a machine or body in motion. The latter is generally given in the form of a graphic record, an important example of which is the diagram of energy or work taken from a prime mover. In both cases the result, whatever it be, whether boundary, area, volume, work, &c., can be found by calculation, but only with an approximation to the truth, depending upon the extent of the calculation. The reason of this is that the data of calculation, which are taken directly in the first case, or selected from the graphic record in the second, only represent actual conditions more or less closely, according as the number of data so taken is greater or less, and the greater the number the greater is the labor of determining the result. The instruments discussed in this paper perform such work mechanically, with the great advantages of rapidity of operation, accuracy of results, and without requiring mental effort on the part of the manipulator; and all this, moreover, to a great extent independently of the complexity of the calculation required. All the results, the measurement of which will be considered, can be represented graphically. If the observations have been made separately, they can be plotted, whether in the form of a diagram of energy, or on the plan or elevation of an area or section, and the boundary can be filled in with a tolerably close approximation to accuracy. In the other case the graphic record is, or may be, directly given. The subject, as far as the theory of the calculation goes, can therefore be studied with reference to such diagrams without the necessity of considering in the first case how they were obtained, and it will be convenient to do this, and afterwards to examine separately various examples of their application. Such diagrams may be drawn upon any kind of surface, and an instrument for dealing with measurements upon that of a sphere will be hereafter described. A plane surface may, however, be employed upon which to represent all cases of any practical importance, and the question thus arises, What are the measurements of the nature under consideration which are required, and which can be obtained from either a regular or an irregular plane of figure?

Such measurements are of three kinds:

(1) The length of its perimeter or boundary.

(2) The area of its superficial contents.

(3) Its relation to some point, line, or other figure on the surface, *e. g.*, its moment of area or moment of inertia about a given line.

All these three kinds of quantities can be ascertained by successive operations of addition. The first requires the addition of elements of length, the second may be obtained by adding up successive elements in the form of strips of area, and the third by adding products obtained by multiplying such strips by some quantity, the magnitude of which depends upon the position of the other point, line, or figure in question. Taking the general case of an irregular figure, it is evident that absolute accuracy can only be obtained when this operation becomes that of integration or summing up of an infinite series of indefinitely small quantities. Instruments for performing this operation are therefore called "mechanical integrators." In all such instruments the rolling action of two surfaces in frictional contact is employed, for this, as will be hereafter seen, enables the conditions of motion to be continuously varied in a way which could not be effected by mere trains of wheel-work, such as form the mechanism of some kinds of calculating machines. This fact necessitates something more than a mere discussion of the mathematical principles upon which the calculations are performed, for though the action of an integrator may be absolutely correct as far as its theory of the performance of the calculation is concerned, yet there is always some instrumental error depending upon the rolling, and also, as will be seen, of the slipping of the two surfaces in frictional contact. This error may be exceedingly small, but it is a matter of great importance to ascertain its exact amount, and the subject will therefore be investigated at length, under the heading "Limits of Accuracy of Integrators," where an account will be also given of the experimental results of Professor Lorber, of Leoben; Dr. William Tinter, of Vienna, and Dr. A. Amsler, of Schaffhausen. In this investigation it will be shown that when integrators are examined upon the mechanical principles of action, they are all found to belong to one of two classes.

(1) In which the surfaces in question slip over each other.

(2) In which only pure rolling motion of the surfaces is assumed to take place.

The significance of this mode of classification is that it not only leads to a clear understanding of the nature of the results to be expected from any particular instrument, and teaches the best method of manipulating it, with regard to its position relatively to the figure to be measured, but it also brings out prominently the mechanical principle upon which the inventor has relied sometimes, as it would appear, unconsciously, for the accuracy of the results expected to be obtained.

It may be here remarked that the same principle, by which an integrator is employed to determine a result from an autographic record, may be applied directly to obtain a continuous result from the machine or body in motion, such, for instance, as an ordinary dynamometer or dynamo-electric machine, from which the autographic record was obtained. Thus, after discussing the action of integrators for dealing with diagrams, it will only be necessary to consider the mechanical details of the instruments for direct application to a machine, and this will be done under the head of "Continuous Integrators."

Coming now to the consideration of the actual measurement of the three kinds of quantities, it will be found that the first is very simple, and, in fact, the only reason why it is not convenient to measure it, by comparing it with the unit of length in the ordinary way, is its continuous change of direction.

The only mechanical method of rectifying a curve, as it is called, that is, obtaining its length as a right line, is by rolling a wheel along it. This wheel is connected with a suitable train of wheels for recording the total number of revolutions, and as the rolling circle of the first wheel is either a unit in length or contains a known relation to this unit, the length of the curve or boundary is given at once by the reading of the graduated wheels. The use of such instruments is very ancient, and Beckmann, in his "History of Inventions," describes amongst various odometers, one mentioned in the Tenth Book of Vitruvius. Such an instrument is made upon a small scale for use by a draftsman, and in one form it is sometimes termed an "opisometer," in another form the chartometer, or Wealemefna; it is also employed upon a large scale as a road or route measurer. The same principle has been em-

ployed in one of the latest forms of anemometer, in which the plane of the wheel is always kept coincident with the direction of the wind, while its edge rolls in contact with the recording surface, and measures the total travel of the wind. In this class falls the device suggested in a letter to "Nature," by Mr. V. Ventosa, of Madrid, for continuously obtaining the N., E., S. and W. components of the wind, a device which was independently arrived at by the author in connection with certain mathematical principles referred to hereafter.

The object of employing a rolling wheel is merely to enable the direction to be changed so as always to coincide with the curve to be measured, and the principle is, therefore, that of direct unit measurement or comparison. The foregoing instrument, which evidently belongs to the second class in which only rolling motion, without slipping, is supposed to take place, forms, however, one kind of mechanical integrator.

The measurement of the other two kinds of quantities is, as in the case of the first, a problem of addition; but, instead of being the addition of an infinite number of infinitely short lines, an infinite number of continually changing magnitudes has to be added. This is the same both for instruments required in the second kind of measurement, or "Area Planimeters," and those required in the third kind, or "Moment Planimeters." From the fact that the changing magnitudes referred to are simpler to deal with in the case of calculating the contents of areas than in finding their moments or any mathematical results of an equivalent kind, the discussion of the theory of the two above kinds of instruments is not the same, and will, therefore, be dealt with under two separate headings.

Area Planimeters.

The area of any plane figure, such as ABDE (Fig. 1), can be obtained in the following manner. Take any straight lines, OX and OY, at right angles to each other, and parallel to OY; draw a series of straight lines equidistant from each other, dividing the figure into a number of strips, or elements of area. A series of rectangles may then be found, as shown at AB, the area of which is equal to that of the corresponding strip, so that, by adding the rectangles together, the area of the whole figure is obtained, as adopted in the common method of finding the area of an indicator diagram. The greater the number of strips the more closely will the height of the two sides of each tend to become equal to each other, and to the height of the corresponding rectangle.

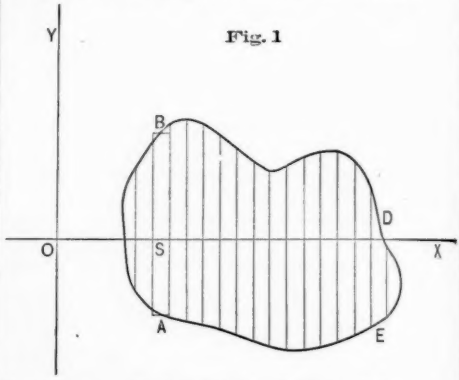
Let Δx = the width of any element of area such as AB, at a distance x from O.

y = height of the corresponding rectangle.

Then $y \Delta x$ = area of the element AB,

and the sum of all such elements of area is the area of the figure ABDE. When

Fig. 1



the number of elements is increased indefinitely, this expression becomes

$$\int_a^b y dx = \text{area of the figure ABDE},$$

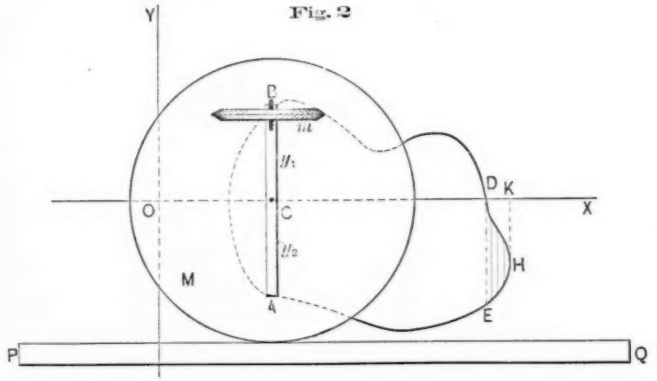
a and b being the extreme values of x, *i.e.*, the limits of integration.

It is evident, therefore, that the area will be correctly measured by an instrument in which the recording wheel or measuring roller always turns at a rate proportional to the ordinate y of the curve, while the body from which it derives its motion moves at a uniform rate along the axis OX.

Area planimeters have been classified according to apparently different modes by which the operation of integration is performed; but, since the action of them all can be explained upon the foregoing principle of adding elements of area, and,

in fact, by means of the same notation, it is not surprising that such classifications are anything but satisfactory. In fact, in one important kind of planimeters, it becomes doubtful to which class they belong, or, whether they should not be placed in two or more classes. It is, without doubt, very convenient to distinguish different planimeters, and, therefore, the names which have been given them will be used; but this will not denote any difference of principle, and the classification which will be adopted is that already explained, and depends on mechanical conditions of action. In what follows, one mode of viewing the mathematical operation is adhered to throughout, and it may be stated that the object of the author has been to make clear the principles of action of integrators, rather than to obtain rigid and exhaustive demonstrations of their theory.

Fig. 2



Planimeters in which Slipping of the Measuring Roller Takes Place.

From a brief account of the subject by Professor Lorber, it appears that the first recorded idea of a planimeter is attributed to Hermann, of Munich, who worked it out with Lämmle. This idea of Hermann's, which was published in 1814, seems to have fallen into oblivion, for in 1827 Oppikofer, of Berne, constructed a planimeter upon similar principles, and it was thenceforth called after his name. On the other hand, Favora gives the priority to Professor T. Gonella, of Florence, who, in 1828, without any knowledge of what Hermann had done, invented and described a very similar instrument. The development of the planimeter seems to have grown out of the instrument of Oppikofer, who, in conjunction with a Swiss mechanic, Ernst, finished a planimeter which won a prize, in Paris, in 1836. Important improvements are due to Wettli, of Zurich, who, with Starke, in 1849, took out a patent in Austria for the instruments now called the Wettli-Starke planimeter. Later on, in England, other inventors (Sang, Moseley) worked at the subject, but all these instruments depended for their action on the same principle, which is as follows:

Let M (Fig. 2) be the plan of a disk rolling in contact with a straight guide PQ, which is parallel to OX, and at a distance from it equal to the radius of the disk, so that the plan of the center of the latter always lies in OX. Let m be a roller upon the surface of the disk, graduated and connected with wheel-work and an index, so that the distance turned through over the surface of the disk can be read in revolutions, or parts of a revolution. The plan of the point of contact (B) of the roller with the disk is always made to coincide with that particular point on the curve, which is in the line drawn at right angles to OX, through the center C of the disk. The plane of rotation of (m) which may be called the measuring roller, is always perpendicular to the disk M, and the plan of its axis, as shown in the figure, is always parallel to OY, so that, in following the curve, it slips backwards or forwards across the surface of the disk, in a direction parallel

to OY. Suppose the disk to roll along PQ for a distance Δx, equal to the width of the element AB.

Then, if y_1 = distance of B from OX.
R = radius of disk M.
r = radius of measuring roller m.
n_1 = consequent reading of measuring roller for this travel of disk.

Then $\frac{y_1}{R}\Delta x$ = linear distance turned through by a point on the disk at a distance y_1 from the center.

$2\pi r n_1$ = linear distance turned through by a point on the circumference of m; but since m rolls on M these distances are equal.

Therefore $$2\pi r n_1 = \frac{y_1}{R}\Delta x,$$

or, $$n_1 = y_1 \Delta x \times \frac{1}{2\pi r R};$$

but $\frac{1}{2\pi r R}$ is a constant, which, by taking r and R in suitable ratio may be made unity.

Then $$n_1 = y_1 \Delta x,$$

that is, the reading of the roller m measures that part of the area of the element above OX.

If the point of contact be made to follow round the curve continuously in one direction, then, when the portion of AB below OX is being measured, the disk is moving in the opposite direction along PQ, but, at the same time, the roller is turning in the opposite way relatively to the disk to that which it was doing before, since the point of contact is now below C. The final result of these two opposite motions is to cause the roller to turn, as at first, and so add the result given for CA to what was given for CB. If the motion of the disk Δx for the width of AB be now regarded as negative,

and $-y_2$ = distance AC

also n_2 = reading of roller for this element of area,

then by similar reasoning to that already used,

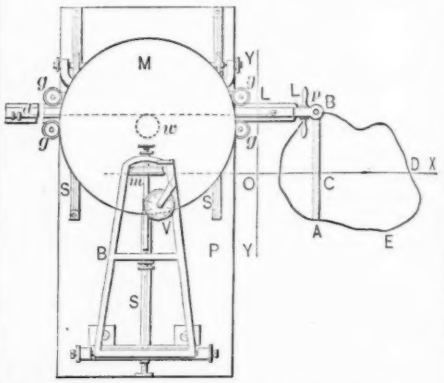
$$n_2 = (-y_2)(-\Delta x)$$
$$= y_2 \Delta x,$$

and $n = n_1 + n_2 = (y_1 + y_2)\Delta x = y \Delta x =$
= area of element AB.

This reasoning holds for any possible position of the roller, or of the axis OX, which may be altogether outside the figure, as it practically is for the integration of the portion DHE. Then it will be found that DKH is subtracted, and DKHE is added, so as to give the required actual area DHE.

Inasmuch as this reasoning is independent of the actual value of the width of the element, and as the vertical motion of the roller m has no effect in theory upon the distance rolled through by it, therefore, in the limit when Δx becomes

Fig. 3



infinitely small, the actual value of the series of infinitely narrow strips which compose the figure ABDE is given by the final reading of the roller when the traverse of the boundary is completed.

The Wettli-Starke planimeter (Fig. 3) acts directly upon this principle, with the exception that it is the disk that is moved according to the changes in y instead of the measuring roller, and the following is a description of the best form of this instrument:

On a base-plate P (Fig. 3), are three guides SSS, along which a frame carrying the vertical axis of the disk M can be moved to and fro. The disk, which is made of glass and covered with paper, has two motions, one rectilineal along the guides, and one of rotation about its axis. The motions are imparted to it by

means of an arm (L), which passes through the roller-guides (*gg*) in the frame carrying the disk, and rotates the latter by means of a German silver wire (*dd*) passing round a cylinder *w* upon its axis, and attached by the two ends to the extremities of the arm. The measuring roller (*m*) rests upon the surface of the disk, being carried in another frame (B), which is hinged to the base-plate. The action is as follows: the base-plate being placed in juxtaposition to the figure to be integrated, any line parallel to the guides, *i.e.*, to the direction of rectilinear motion of the disk, may be taken as the axis OY; and line OX, drawn through the edge of the roller, perpendicular to OY, may be taken as the other axis. Then, as the pointer *p* at the extremity of the arm is made to pass round the boundary of the figure, the disk will be turned through a distance proportional to the travel along OX, while at any instant the roller (*m*) is at the same distance from the center of the disk as the pointer is from OX.

If y_1=CB=mean height of element Δx= =width of element AB.

Then, by the reasoning already given, the reading of the roller which the pointer passes over the upper boundary of the element AB, is

$$n_1 = y_1 \Delta x,$$

and the final reading of the roller is

N=area of the figure ABDE.

Hansen, in 1850, still further improved this instrument, and, in conjunction with Ausfeld, introduced a different method of reading the result, and of carrying the frame, this instrument being known as the Hansen-Ausfeld planimeter. Various other instruments of the same kind were shown in the Great Exhibition of 1851, but in all, the motion of the arm carrying the pointer was "linear;" that is, the motion, which must be possible in every direction, is obtained by compounding two rectilinear movements, at right angles to each other. Such instruments are therefore called "linear planimeters."

Many different forms of linear planimeters have been suggested, but the only modification of the disk and roller which it will be worth while to notice is the

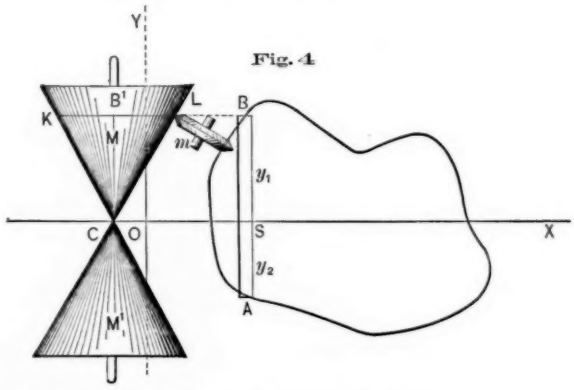


Fig. 4

cone and roller.

Let MM′, Fig. 4, be the cone corresponding to the disk M, and rolling on the edge of its two bases in a direction parallel to OX. Let the roller *m* always be in contact with a circle on the cone, whose center B′ is at a distance CB′ from the apex C of the cone, such that

CB′=SB=y=mean ordinate of element SB.

where the element AB is being at that instant integrated. Adopting the same notation as before, when the cone has rolled over the surface through a distance Δx, then, whatever be the angle of its apex, the distance rolled through by the roller *m* is

$$2\pi r n_1 = \frac{y_1}{R} \Delta x,$$

or

$$n_1 = y_1 \Delta x \times \frac{1}{2\pi r R}.$$

As might have been anticipated, the expression is the same as was obtained in the case of the disk, the latter being a special case of the cone when the vertical angle is 180°.

Thus the cone may be employed instead of the disk, and such an instrument was invented by Mr. E. Sang, who, in 1852, published a description of it, according to which the action was extremely accurate, but it does not appear to have come into very extensive use.

No more instruments of the kind will be described, since they have given place to those in which the arm carrying the pointer turns about a center or pole, and which are, therefore, called "polar planimeters."

In the year 1856, Professor Amsler-Laffon invented and brought before the world the now well-known polar planimeter bearing his name, and, since then, no less than twelve thousand four hundred of these instruments have been made and sent out from his works at Schaffhausen. According to authorities, which Professor Lorber quotes, Professor Miller, of Leoben, invented independently a planimeter of this kind in the same year (1856), which, being made by Starke, of Vienna, is known as the Miller-Starke planimeter. Previous to this, in 1854, Decher, of Augsberg, as well as Bouniakovsky, of St. Petersburg (1855), had improved upon previously-existing forms of polar planimeter, though it is well to note that the planimeters already mentioned as sent to the Great Exhibition of 1851 from various parts of Europe, as Italy, Switzerland, France, and Prussia, were all linear, and no mention is made of polar planimeters in the jurors' report.

The Amsler planimeter is shown in Fig. 5. It consists of two bars, (*a*) the radius bar, and (*b*) the pole-arm, jointed at the point C. The tracing point *p*, which now coincides with the point B of the figure ABDE, is carried round the curve, and the roller *m*, which partly rolls and partly slips, gives the area of the figure; and by means of the graduated dial *h*, and the vernier *v*, in connection with the roller *m*, the result is given correctly in four figures. The sleeve H can be placed in different positions along the pole-arm *b*, and fixed by a screw *s*, so as to give readings in different required units. A weight at W is placed upon the bar to keep the needle-point in its place, but in instruments by some other makers T is a pivot in a much larger weight, which rests on the paper. A recent minor improvement has been to fix a locking spring to the frame, so that the roller can be held when the planimeter is raised for the purpose of reading it.

The theory of the polar planimeter may be simply deduced from that of the disk and roller thus:

Let Fig. 6 represent the same disposition of the disk M with regard to the

Fig. 5.

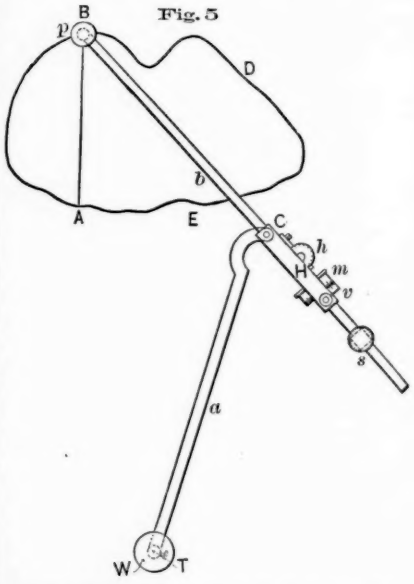


figure ABDE, as in Fig. 2. but now let the roller *m* move round the edge of the disk instead of across it, its distance from OX being always the same as before, viz.:

$$Oq = SB = y_1.$$

The turning of *m* for a given travel, $\triangle x$, of the disk is found thus—draw *lq* (Fig. 6A) tangent to the disk at *m*, so that

$$lq = \triangle x,$$

and draw *lk* parallel to the axis of rotation of *m*, then *qk* is the distance turned through, and *lk* is that slipped through by the edge of the roller *m*, when the disk has rolled through a distance $\triangle x$;

therefore, using the same notation as before,

$$qk = 2\pi r n_1$$

and $$\frac{qk}{lq} = \frac{2\pi r n_1}{\Delta x} = \sin \angle qlk;$$

but in Fig. 6 $$\frac{Oq}{Sq} = \frac{y_1}{R} = \sin OSq.$$

But by similar triangles

$$\angle qlk = \angle OSq = \alpha;$$

parallel to OX. The turning of m thus measures the area of the element as long as y does not change. If, however, the value of y changes so that m changes its distance from OX, the measuring roller is likewise turned a certain additional amount from this cause; but this does not affect the correct reading of the area so long as its first and last positions are equally distant from OX. The reason is, that then the roller has turned as much in one direction in moving away from OX as it has in moving towards it, and this is the case for the initial and final positions of the pointer when the complete travel of the closed curve has been made. Now, inasmuch as the velocity of the edge of the disk is just the velocity at which the center has been shown to move along OX, the disk may be removed altogether. The roller is then moved in contact with the surface of the figure and with identically the same amount of turning as before, provided that its plane of rotation is turned so as to make the same angle with OX (which is now its direction of translation), as it did before with the direction

Fig. 6A

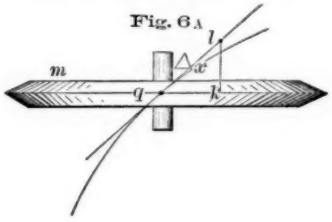
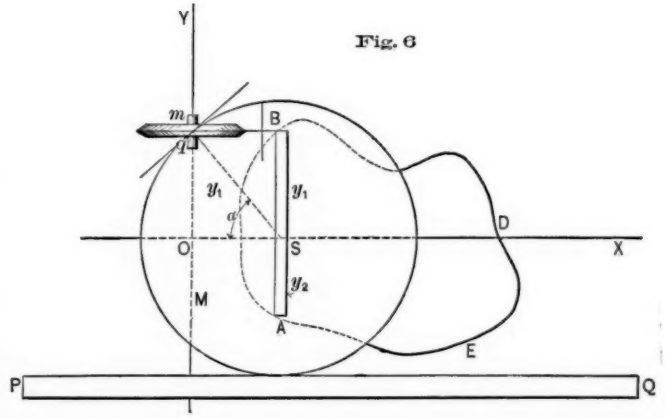


Fig. 6



Therefore $$\frac{2\pi r n_1}{\Delta x} = \frac{y_1}{R},$$

or $$n_1 = y_1 \Delta x \times \frac{1}{2\pi r R}.$$

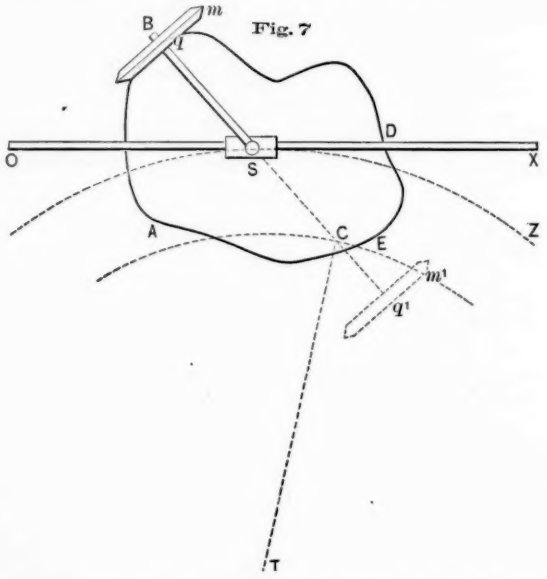
This is the same result as previously obtained, and it has been given in this way because there is an important class of planimeters to be hereafter described, combining the polar planimeter with the disk and roller, in which a principle is employed which is thus made obvious. This principle is that the turning of m is exactly the same as if it were in contact at the point B, no matter in what position it may be along the line through B

of motion of the edge of the disk in contact with it. This is the case when it is turned through that angle, and then its axis of revolution coincides with the radius S*q*.

In order to keep the direction of the plane of rotation always at right angles, it is only necessary to have a rod or bar S*q* capable of turning on a pin at the point S. The pin at S is attached to a sleeve, which can freely move along a guide-bar, whose direction coincides with the axis OX. By employing the bar qSq' itself as the axis of rotation on which *m* turns, the simple planimeter shown in Fig. 7 is obtained, in which the point of contact of the measuring roller is made to pass around the diagram. The turning of the roller *m* correctly gives the superficial contents. The roller can be moved to any position on the rod, such as shown in dotted lines, Fig. 7, without in any way affecting its resultant turning, and the former point of contact of the roller is replaced by a pointer, which is made to follow the curve instead of the roller. Professor Burkett Webb has described to the author a planimeter of this form used in the United States, known as "Coffin's" planimeter.

If, finally, the point S, instead of moving along the straight line OX, which may be considered as a portion of a circle with its center infinitely distant, moves along the arc SZ (Fig 7), or any other arc, as, for instance, that with radius TC, the instrument becomes the ordinary Amsler planimeter (shown in dotted lines). This explanation, so far, is based upon that given by Sir Frederick Bramwell, who has further shown that the change from the motion in a straight path to that in the arc of a circle has no effect upon the ultimate reading when the complete travel around the closed curve has been made, and the arm SB has returned to initial position. The following demonstration of the truth of this appears, however, to have an advantage, in that it follows throughout the operation of integration, especially as recent planimeters are more complicated than that of Amsler.

Fig. 7



1st. Let point S (Fig. 8), at the extremity of the radius rod, move along the broken line STUVWXYZ, and from these points draw arcs with a common radius=R, cutting the curve in points t, t_1, u, u_1, v, v_1, &c., *s* and *z* being tangent points at the end of the curve from the points S and Z. The proof has already been given that the integration of the

complete portion st_1t_2, taken separately, is given by the reading of the measuring roller; so also are given the areas of the various other portions, $t_1u_1u_2t_2$, &c. If the separate portions were integrated consecutively, any arc, such as t_1t_2, would be traversed in both directions by the measuring roller, because it would move one way around in traversing one figure and the apposite way in going around the adjacent one, and the reading due to the arc would be eliminated.

Thus the whole curve may be integrated correctly at once without going round each separate portion formed as above, even if the point S at the end of AB moves upon a broken line instead of along OX. Next, substitute a continuous curve TUVXYZ (Fig. 8A) for the broken line. This curve may be supposed to consist of an infinite number of straight portions. The infinitely small portions contained between an arc, as u_1u_2, and another very close to it, drawn from the beginning and end of these straight portions, may, just as in the case of the broken line, be supposed to be integrated separately and with a correct result, which is independent even of a possible crossing of the arcs, as v_1v_2 and u_1u_2. In the same way as before, it may be seen that the arcs u_1u_2, etc., need not be traversed and, so long as the point S returns to its initial position, the area of the figure is given by the simple traverse of its boundary, whatever be the curve on which the point S moves, which, in the case of the Amsler planimeter, is a circular arc.

Various writers have explained the action of the simple polar planimeter in ways more or less different. One of these ways, recently given by Mr. F. Brooks, of Lowell, U. S., may be alluded to. He shows that the area may be

Fig. 8

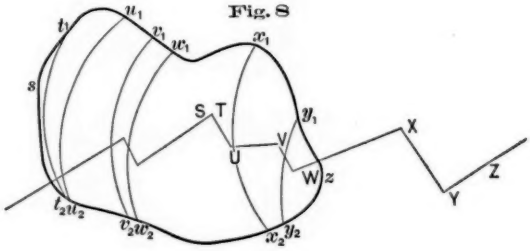
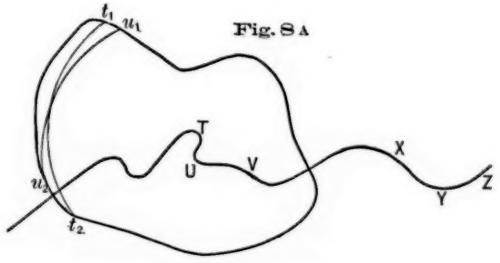


Fig. 8A



treated as the difference between the area swept out by the line Tp (Fig. 9) and the sector of the zero circle, or circle upon whose circumference the pointer (p) being moved, the measuring roller is not in consequence turned. This is true, both for the outside or inside, if proper signs be taken. Let the element of area pq be passed over, the curve at p being for a small distance considered concentric with the zero circle, this small area subtending an angle w at the center; then, if values be taken as shown upon Fig. 9, in which

CT = radius-bar = a;

Cp = one portion of pole-arm = b;

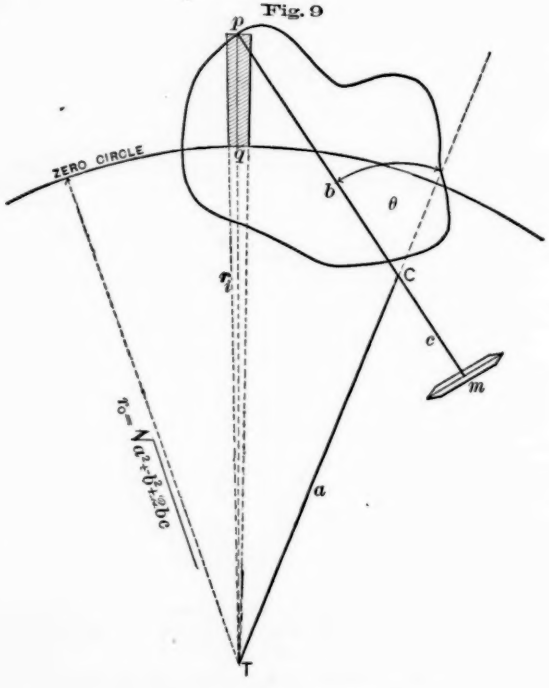
Cm = the other portion of pole-arm = c;

Area $pq = \frac{1}{2}w\,(a^2+b^2+2ab\cos\theta) - \frac{1}{2}w\,(a^2+b^2+2cb) = wb\,(a\cos\theta - c)$,

and, by a geometrical construction, the travel of the measuring roller is easily shown to be equal to the same expression. Mr. Brooks also explains why the area of the zero circle must be added to the reading if the figure to be integrated contains the center T. The following appears, however, to be a still simpler explanation. Referring to Fig. 7, it is evident that going around the outside of the zero circle corresponds to a movement taken continuously above the zero line OX when only the portion above OX is measured. In this latter case the curve could never be completely traversed as long as the pointer moves in one direction. Suppose, however, that the ends of OX are bent round and brought within the figure, then the motion in one direction will enable the complete circuit to be made; but only the portion outside the line, *i. e.*, corresponding to that originally above OX, will be measured by the roller, and that within must consequently be added to the recorded result. This quantity is evidently the area of the zero circle in the case of the Amsler planimeter, which must, therefore, always be added to the result when the center of the radius-arm is within the diagram to be measured.

As the Amsler planimeter alone, so far as the author is aware, has been modified to measure the area of any non-developable surface, this modification may be here noticed. The only surface of the kind to which it has been adapted is a spherical one. Fig. 10 shows the instrument, and from that figure it will be seen that the chief alteration is the placing of two joints *j j'*, one upon the radius-bar (*a*), and the other upon the pole-arm *b*, so as to allow the employment of the integrator for surfaces of varying curvature. The joints are equidistant from the end of each bar, and exactly opposite to each other—the radius-bar and pole-arm being now of equal length, and a pin *f* is placed on (*a*), which fits into a corresponding recess in

Fig. 9



(b), so that when the two arms are closed, they can be together bent at the joints to the required amount, and, the joints being purposely made stiff, they will remain at the proper angle when the instrument is used. The joint (j) acts so that the tracing point (p) is always in the place of the axis of rotation of the measuring roller. The theory of the action of this instrument has been fully explained by Professor Amsler, in an article in which the theory of the relations between measurement upon a spherical surface and upon a plane surface is discussed.

S. This setting causes the reading of the instrument, when the diagram is traversed by the pointer in the usual way, to give at once the mean height of the diagram in fortieths of an inch. The simple relation is as follows:

$$\text{Reading of measuring-roller} = \frac{}{40} = \text{Mean height of diagram in inches.}$$

Mean pressure = Mean height × vertical scale of diagram.

As an instance of the great saving of labor by the use of the Amsler planimeter,

Fig. 10

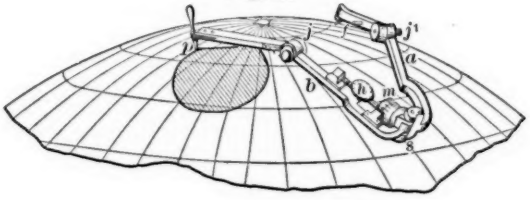
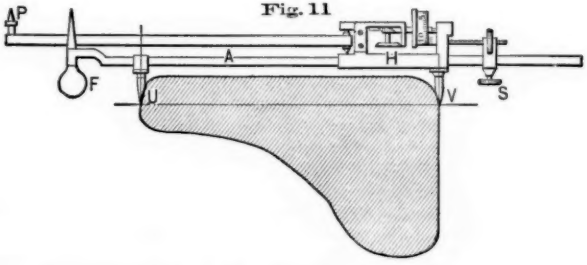


Fig. 11



The various applications of the simple planimeter for finding areas are well known, and need not be explained; but there are some slight modifications of the instrument for special purposes, and one of these recently applied by Professor Amsler to his planimeter is worth noticing. This is illustrated at Fig. 11, and is a device for reading at once the mean pressure given from an indicator diagram. Two points, U and V are seen, one (U) being upon the upper side of the bar A, which slides in the tube H, and one (V) upon the tube H itself. These points can be adjusted to the length of the diagram by inverting the instrument in the way shown in the figure, and the sliding-bar is then clamped by the screw

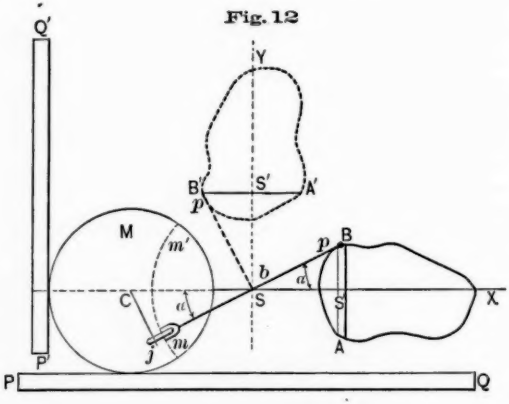
the author happens to know a civil engineer's office, where a large amount of earthwork quantities had to be taken out, the calculations proceeded slowly and with many repetitions, until one of the draftsmen procured a planimeter, and then the other, with the result of a great expedition of the work, and almost the complete absence of errors—and even then only in decimal places—where previously the divergence had been as much as by units.

Although the connection between the disk and roller or linear planimeter and the polar planimeter has been shown, it is possible to regard them as acting upon different principles. The former may be considered as measuring the variation in

the ordinate (y) by a change of effective radius of the circle on which the measuring-roller works, the latter measuring the same thing by a corresponding change in the sine of the angle which its plane of rotation makes, with its direction of motion over the surface on which it rolls. They have, in fact, been classified in this way as radius machines, and sine or cosine machines, for the slipping, although occurring in both, appears in the ordinary way of viewing the subject to affect the result in different ways. In the former, slipping is supposed to be entirely due to the variation in the value of (y), and only takes place when the ordinate changes in value; in the latter, the change is supposed to be effected by turning the pole-arm about its center, without any slipping at all. This distinction is, however, quite an imaginary one, for it will be seen that if the curve be obliquely inclined in either case to the axis OX, the action of the measuring roller is precisely the same. Recently, a large number of what are called "Precision Polar Planimeters," have been designed and constructed, which combine in an obvious manner the above two principles of action, the disk giving motion to the roller, while the pole-arm carries it across the disk in an oblique direction. Thus, the advantages of a uniform and invariable surface of contact for the roller, and the convenience of the polar planimeter are combined, with the still more important advantage of a large relative turning of the measuring roller. Before describing a few different forms of the best of these instruments, the general theory upon which they work will be given; it will then not be difficult to understand the action of the several instruments without repeating the explanation in each case. It will be found that both the linear and polar planimeter are only special cases of application of the general principle upon which the correctness of action of precision planimeters depends.

It will be well to approach the matter from the same point of view as in explaining the linear planimeter. Let the disk M, Fig. 12, rotate about an axis C as it

Fig. 12



rolls along the line PQ, parallel to OX, the pivot on the axle at C being attached to a frame which also carries another pivot S. This latter pivot always lies upon OX, and about it rotates a pole-arm b, carrying a pointer p at one end, and the measuring-roller m at the other end. The plane of rotation of the measuring-roller coincides with the direction of the pole-arm, and is carried over the disk in contact with it, along the arc mm'. Then from what was proved, p. 402, the motion of the roller m is exactly the same as if it were moved, so that its axis always coincides with Cj, the perpendicular upon the pole-arm from the center of the disk —provided only that its axis is always parallel to this line. Thus, adopting the previous notation, and taking

Sp=length of upper portion of pole-arm=R.

Then when the disk rolled through a distance Δx,

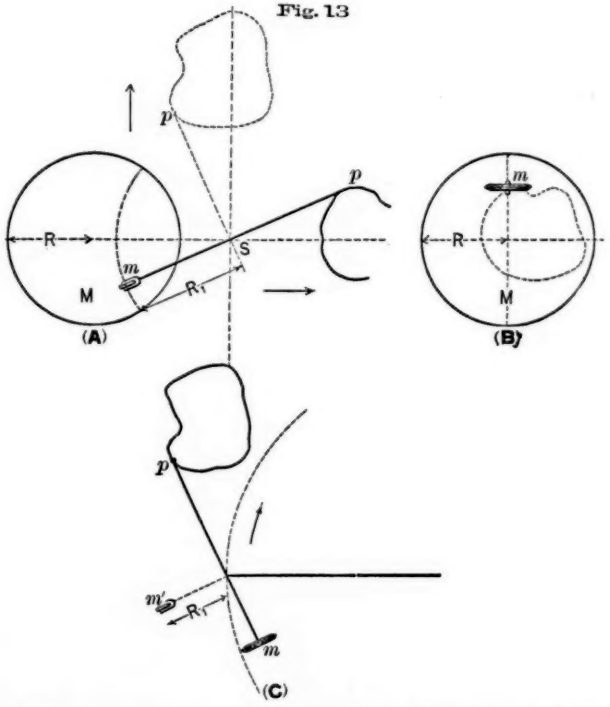
n_1 = reading of roller m

y_1 = ordinate SB.

$$\frac{\text{turning of roller}}{\text{distance turned by edge}} = \frac{2\pi r n_1}{\Delta x} = \frac{Cj}{CS} = \sin a;$$

arm S must be taken parallel to the guide P′Q′, that is, perpendicular to the former direction. It has already been shown in the case of the Amsler planimeter, that it does not matter in what path the center S of the pole-arm is carried, so long as the foregoing conditions are observed, and thus there are several forms of precision polar planimeters in which the point S is carried in the arc of a circle

Fig. 13



but $$\frac{S'B}{SB} = \frac{y}{R} = \sin a;$$

therefore $$\frac{2\pi r n_1}{\Delta x} = \frac{y}{R},$$

or $$n_1 = y \Delta x \times \frac{1}{2\pi r R},$$

which is the same result as in the case of both the linear and polar planimeters. In practice, the portion of the pole-arm which carries the pointer is usually perpendicular to the other portion, as shown by the dotted lines, Fig. 12. In this case, the direction of motion of the disk and frame carrying the center of the pole-instead of along a straight line. It may now be made clear, from Fig. 13, that the first two kinds of planimeters are special cases of the last.

(A) Fig. 13. Let R be the radius of the disk, R_1 the radius about which the roller m is carried. Then the area of the diagram as already explained can be measured by either pole-arm Sp or Sp'.

(B) Fig. 13. Let the radius R_1 of the pole-arm become infinitely great, while R remains finite; thence m moves across the disk M in a straight line usually, but not necessarily, through the center, and the linear planimeter is the result.

(C) Fig. 13. Let the radius of the disk become infinitely great, and any motion of such an imaginary disk under these conditions would make the result equivalent to moving the roller over the surface of the paper. Therefore the disk may be removed, and the elementary form of polar planimeter is obtained, the roller being placed in either position as shown at m or m', without affecting the result.

The following is a simple explanation of the action of the precision polar planimeter:

Let M (Fig. 14) be the disk, which can be turned by any suitable means through a distance corresponding to the linear travel of its center about C.

Fig. 14

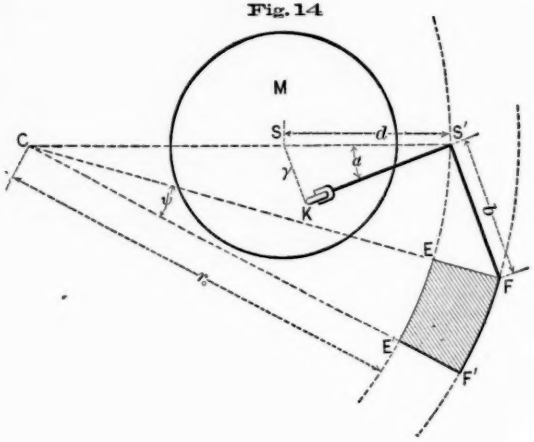


Fig. 15

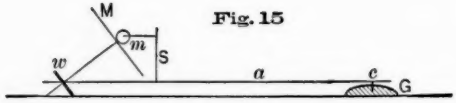
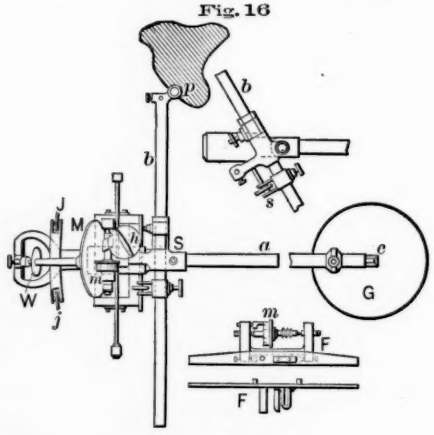


Fig. 16



Let r_0 = radius of zero circle (E′ES′).
r = radius of any circle FF′.
a = ∠ turned through by pole-arm, when the pointer moves from the zero circle to the circle FF′.
ψ = ∠ turned through by radius arm, CS, when an element EE′ F′F is being described.

where c and d are constant quantities; also if ρ equal the radius of the roller.

then $\frac{y}{R}$ = linear distance by edge of roller / distance traveled by edge of disk

$$= \frac{2\pi\rho n_1}{r_0\psi c};$$

$$\therefore y = \frac{2\pi R\rho n_1}{r_0\psi c};$$

Fig. 17

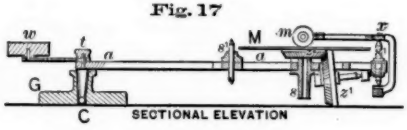


Fig. 18

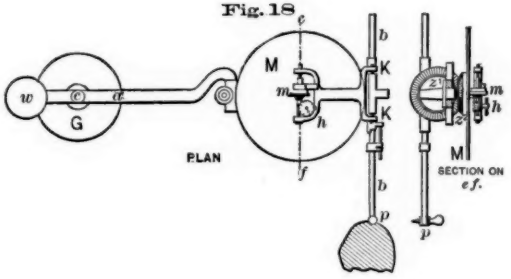
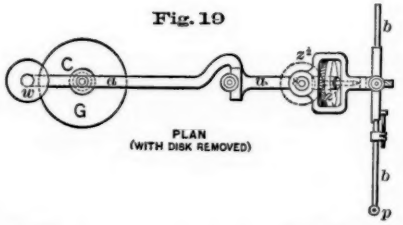


Fig. 19



a = radius arm = CS′.
b = pole-arm = FS′.
d = SS′.

Then from the figure—

and $r_0^2 = a^2 + b^2$

$r^2 = a^2 + b^2 - 2ab \cos(90 + \alpha)$

$= a^2 + b^2 + 2ab \sin \alpha.$

Therefore $r^2 = r_0^2 + 2ab \sin \alpha,$

or $\sin \alpha = \frac{r^2 - r_0^2}{2ab}$

Now the turning of the plate is proportional to ψ, and may, for the arc FF′, be taken as equal to $r_0\psi c$.

$y = SK = SS' \sin \angle SS'K = d \sin \alpha,$

Therefore $\frac{2\pi R\rho n_1}{r_0\psi c} = d \sin \alpha = \frac{d \times (r^2 - r_0^2)}{2ab}$

or $n_1 = \frac{r^2 - r_0^2}{2}\psi\left(\frac{r_0 cd}{2\pi R\rho ab}\right);$

but $\frac{r_0 cd}{2\pi R\rho ab}$ is a constant quantity, and may be made equal to unity.

Therefore $n_1 = \frac{r^2 - r_0^2}{2}\psi$ = area of element EE′FF′.

Thus n_1 is a measure of an element of area, and as the motion of m due to the turning of the pole-arm in moving to a

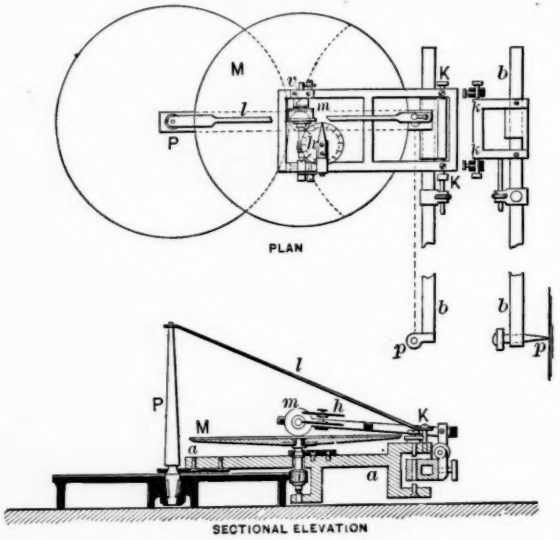
larger or smaller circle does not affect the reading when the pointer at F has passed round a closed curve, the final reading of the roller gives the area of any figure.

The actual construction of the precision polar planimeter appears to have been first carried out by Mr. Hohmann, Bauamtmann of Bamberg, in 1882, in conjunction with the well-known mechanician Mr. Coradi, of Zurich. A plan of the first instrument is given in Fig. 16; but it will be more easily understood by reference to the diagram, Fig. 15, which shows a frame (*a*) pivoted at one end (*c*) to a weight (G), about which it turns. This frame carries a small disk (*w*), which rolls in contact with the surface of the diagram, and gives motion to the disk M. The roller *m* is moved across the disk in the horizontal direction by a pole-arm centered on S as axis. Referring to Fig. 16, which is lettered in a similar way to Fig. 15, it will be seen how the pole-arm, in turning about the center S, effects this motion. A plan and elevation of the frame F, which carries the roller *m*, is shown on a larger scale, and this frame is moved backwards or forwards through a slot in the supporting frame. The roller *m* has the arrangement of the screw and worm for obtaining the readings of the dial *h*, as in the Amsler planimeter, and also the vernier in conjunction with the measuring roller. Two rollers, *j j'*, serve to balance the instrument. The details of the arrangement by which the length of the pole-arm *b* is adjusted are also shown on a larger scale.

In this instrument, the fact that the disk is inclined at an angle makes no difference in the theory of its action, and as the roller W obviously drives the disk so that the angular motion corresponds with the angular motion of the radius bar *a*, the explanation already given makes its mode of operation clear. The case is rather simplified by the fact that the roller *m* is moved radially across the disk.

An instrument of similar kind has been designed and recently described by Professor Amsler-Laffon. This is shown in Figs. 17, 18 and 19, where it will be seen that this disk M, which is now horizontal, is turned by means of bevel-wheels z_1 z_2, the back of one of which forms a portion of a frustum of a cone rolling about the center C of the radius-arm *a a*.

Figs. 20 and 21



The center is itself a sphere, which allows any side motion of the instrument due to the inequality of the surface to take place without affecting the accuracy of the result. The necessary pressure of the centers being purposely adjusted to effect this. The frame can be taken off one center, s' (Fig. 17), by unscrewing a set screw at x, and at once placed upon the other. The weight w can be adjusted

Fig. 22

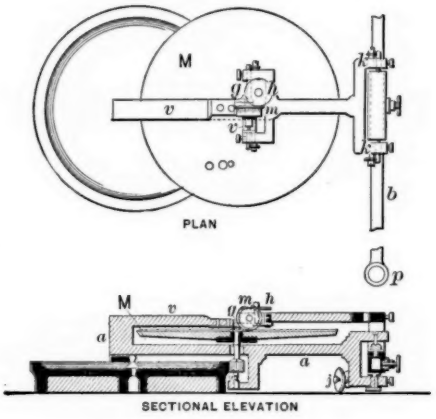
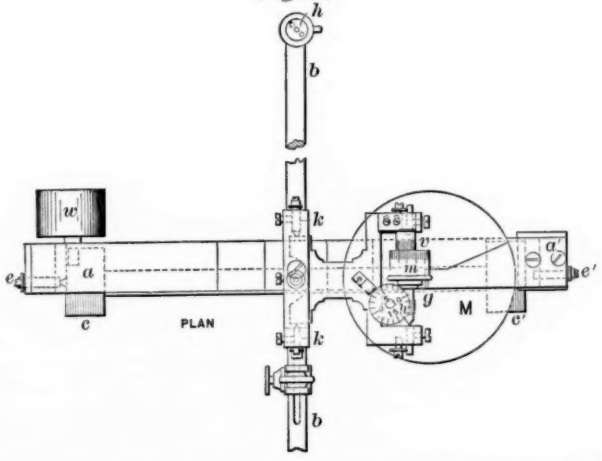


Fig. 23



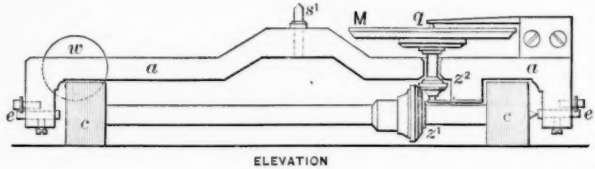
the roller upon the disk is obtained by allowing the weight of the portion of the frame b which carries the roller m to rest upon the disk by being pivoted by the centers KK (Fig. 18). A peculiar feature of the instrument is that the pole-arm frame can be centered either within or without the frame. If placed in the former position, the reading is twice as great as in the latter, the positions of in any position by means of the nut and screw t (Fig. 17), and so the pressure of the pointer p upon the surface of the diagram may be regulated.

In both the above instruments the disks derive their motion from a roller in contact with the surface of the diagram, but in the next two instruments to be described, Messrs. Hohmann and Coradi have caused the disk to be turned in

a manner which prevents any such error as from the possible slipping of the above roller. The first instrument of the kind is shown (Figs. 20, 21) in plan and elevation. The disk M is carried by a frame (*aa*) as before, but the frame now swings about a circular stand, the edge of which is toothed, so that the pinion (*i*), which is upon the axis of the disk, is turned, and therefore the disk itself, with the same angular velocity. The weight of the frame and disk is, to a great extent, taken off by means of the light rod (*l*), which swings about a central pillar P. A side view of the pole-arm is shown, and the mode of adjusting it and supporting the portion which carries the roller (*m*), so that by means of centers KK the weight of that portion of the frame is allowed to rest upon the disk.

It is evident that this instrument works upon identically the same principles as the foregoing ones. This "Freely swinging" precision planimeter was followed by another, called the "Plate" planimeter (Fig. 22), which is of still simpler construction. In this form advantage is taken of the fact that the measuring roller need not have its path through the center of the disk, and a support (*v*) is obtained above the disk, so that its pivot (*q*) can work between cen

Fig. 24



Figs. 25,26 and 27

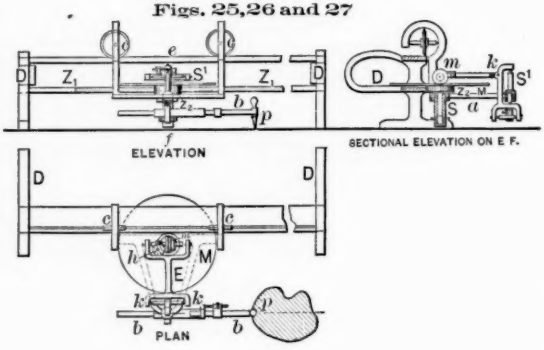
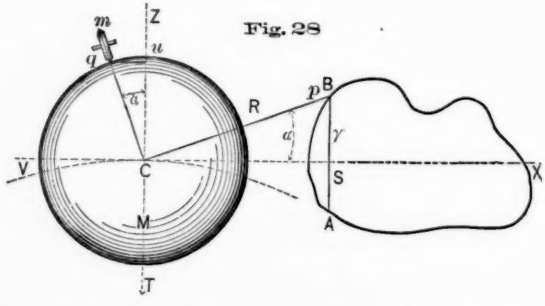


Fig. 28

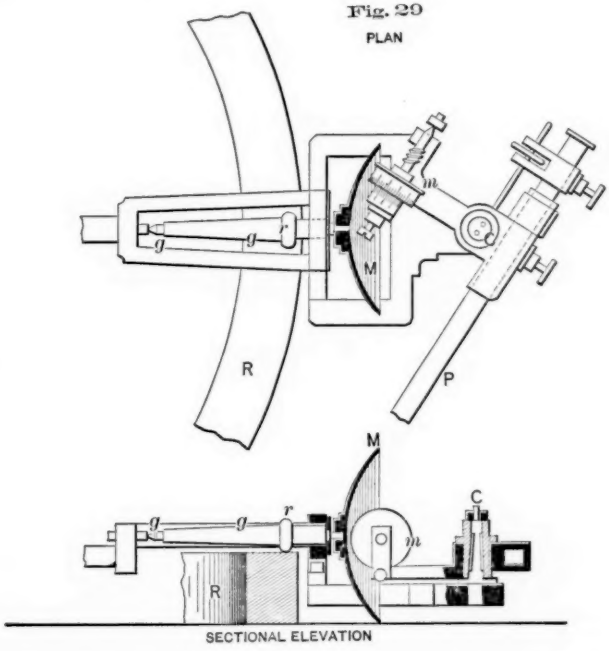


ters, the weight of the frame being supported by rollers (*j*). The portion of the pole-arm which carries the roller (*m*) is (as in the last case) pivoted between the centers KK. The dial for higher readings is as in the case of the previous instruments denoted by *h*.

The last and most recent modification is the "Rolling planimeter," of Coradi. This approaches nearest to the diagram

works upon the centers *ee*, which are set-screws in the frame (*aa*). The disk M is also carried between centers (*qq*), as in the instrument last described, and, also, as in that case, the path of the roller does not pass through the center of the disk. This instrument, which has many advantages, and, notwithstanding that it rolls on the diagram surface, gives results of great accuracy, has been examined with

Fig. 29



(Fig. 12), which completely explains its action. Here the center of the radius-arm is removed to an infinite distance, and the center of the disk and that of the pole-arm are carried along straight lines parallel to the axis OY in that figure. The way in which this is effected is seen from Figs. 23 and 24, which show Coradi's rolling planimeter in plan and elevation. Two rollers (*cc'*) are in contact with the surface of the diagram, and on their axis is a bevel wheel (z_1) (Fig. 24), which gears with another bevel-wheel (z_2), which is upon the axis of the disk. Thus the wheels z_1 z_2 are turned as the frame is rolled along, and, consequently, the disk itself. The axis of the rollers *cc* great care by Professor Lorber, who has given a lengthy description of it and a full account of its theory.

The last planimeter of this kind to be examined is one by Professor Amsler. This instrument, shown in Figs. 25, 26, 27, differs from the last in that the tooth-wheel z_3 works in gear with a rack z_1 z_1, which is cut upon a fixed frame DD. Thus, although it is supported by the rollers *cc*, there is no possibility of slipping as far as the turning of the disk is concerned. The rollers run in a groove cut in the frame DD, and the action of the instrument is easy and smooth. The theory of its action is identical with that of the foregoing one, as explained by

means of the diagram (Fig. 12). The various parts are lettered in the figures to correspond with the explanations of that instrument previously given.

In the instruments hitherto described the surfaces of revolution are limited to the disk and cone, but various other surfaces may be made to replace these. The only one that has been so employed is that of the sphere; and in the present class of instruments, in which slipping takes place, the following property of the sphere is made use of: Let a sphere M (Fig. 28), which replaces the disk (Fig. 2), roll along the axis OX. Then suppose the roller m can, by suitable means, be moved round the surface so that its plane of rotation shall always contain the center of the sphere and be perpendicular to the arm CB, which corresponds to the pole-arm of the former instruments; it is evident that if the perpendicular be drawn from q, the point of contact of m with the sphere, to CZ the axis of rotation of the sphere, meeting it in the point u, the line qu is the radius of the rolling circle of contact of the measuring roller.

Therefore $$\frac{\text{motion of measuring roller}}{\text{motion of sphere along OX}} = \frac{qu}{\text{CV}} = \frac{qu}{q\text{C}} = \sin a.$$

But from the figure $$\frac{\text{SB}}{\text{CB}} = \frac{y}{\text{R}} = \sin a.$$

Therefore, adopting the same notation as hitherto used,

$$\frac{\text{motion of } m}{\text{motion of M}} = \frac{2\pi r n_1}{\Delta x} = \frac{y}{\text{R}}$$

$$n_1 = y \Delta x \times \frac{1}{2\pi r \text{R}},$$

which proves that the area of the curve may be measured by any device, on the principle of Fig. 28. It may be shown in the same way as on p. 18, that the result is similar if the sphere rolls upon the arc of a circle, about any center as T, instead of along the straight line OX. Planimeters of this kind have been constructed by Mr. Hohmann and Professor Amsler. In both cases only portions of the whole surface of a sphere have been employed, and the motion is given by means of an axis, instead of by rolling the spherical surface upon the diagram. In Mr. Hohmann's planimeter, shown in plan and elevation, Fig. 29, the concave surface M is used. Rotation is given to this by means of an axis gg, an enlarged portion of which (r) rolls upon a circular metal path R. The pole-arm P turns about a center c, and so causes the rolling circle of the measuring roller m to vary according to the foregoing principles. This instrument has not come into use. Professor Amsler has employed the convex surface in an instrument somewhat similar to the one described, except that better provision is made for obtaining the required pressure between the surface of the roller and sphere, and for giving rotation from the roller-path.

HOW MUCH VENTILATION?

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Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE topic Ventilation has been treated by so many writers, and from so many points of view, that it may seem unnecessary to dwell upon it any further. The apology for doing so lies in the desire to clear away from the minds of some people a feeling that the asserted requirements of ventilation are made by enthusiasts and hobby riders. This impression, more or less vague though it be, possesses many practical men, influential in their professions.

And why, it may be asked, are they thus influential? Is it not because of devoting their attention to some one branch of work, becoming specialists in that branch? They naturally resent the rejection of their *dictum* by any one who has not by special training fitted himself to judge the matter; even as the architect would look with disgust upon the surgeon who asserted that he could build houses because he had studied the framework of the human body. They demand

faith on the part of others in their assertions, and rightly so, but they must make a like return. This law of reciprocity is an essential requirement of specialism, which word is at the very foundation of success in modern arts and modern scientific work.

Therefore, when men of talent, who have given their time to the study of hygiene and kindred subjects, assert certain facts and give certain data regarding ventilation, let us believe that there is some basis for what they say, and that the data which they give us are correct. There is a definite, *practical* reason, and, therefore, a scientific one, for the assertion that under ordinary circumstances a human being requires a given amount of fresh air in a given time, for health. The fact that he can be proved to have lived to old age on a much smaller allowance is no argument against it, any more than is the fact of persons living to old age in poverty an argument against the expense of a table well supplied with healthy and nourishing food.

An attempt may be made to rehearse the main features of the reasoning that leads to the requirements of modern science regarding amounts in ventilation. It will, perhaps, serve to help the faith of some doubting or skeptical person, puzzled by seeing thousands living around him in apparent health and in blissful ignorance that there is such a thing as bad air.

In the first place, the object of ventilation of buildings is to provide air for the inmates that shall be healthy for breathing, and not disagreeable to the senses. This necessitates a change of air, because operations are constantly going on that tend to make it objectionable. What are these operations? First in importance is man himself, not because he is always the chief source of vitiation, but the calculation of the amount required by him must generally be considered, for he is always present where ventilation is needed. After man come what may be styled the accidental source of vitiation, such as gas lights and lamps, gases from stoves and poor furnaces, the odors of the various domestic operations, and the gases and mechanical impurities arising from different manufacturing industries. Some would also include the gases and disease germs which in too many houses escape from drainage pipes into the rooms. It does not seem consistent, however, to allow in a statement of sources of impurity to be recognized and allowed for, one that should never be tolerated for an instant.

All the special sources of vitiation are variable in amount and in occurrence. They may cease entirely. Not so with man. He is a pump for inhaling pure air and exhaling bad air, and the machine keeps on its pulsation day and night, winter and summer, until death removes the power and the breath ceases. It is easy to see the propriety, therefore, of basing the air supply on his requirements, that is, on the number of people to be supplied, and then making such allowance as may be necessary for special sources of vitiation. This is the only sound, scientific ground to start from, for it will support all cases, from those in which a large gathering of people is the only source to be allowed for, to one where the number of beings present bears only a small proportion to the special causes of impurity.

The methods of ascertaining the requirements of man regarding air supply may be outlined in this wise. Carbonic acid (CO_2) is exhaled with the expired air, also organic matter and vapors that are the natural outcasts of the body, as well as those proceeding from an unhealthy state of the system. Water is also evaporated from the lungs and exhaled as vapor. In addition to all these, is the operation of transpiration from the pores of the skin, whereby moisture and various organic secretions are given off to the surrounding air. An adult gives off $1\frac{1}{2}$ to $2\frac{1}{2}$ lbs. of water per day in this manner. A person suffering from certain diseases will also infect the air with disease germs, that make it extremely dangerous for breathing. This is not the place for a discussion of the germ theory of disease; suffice it to say that these living germs are well attested to, are exceedingly minute, extremely active, and that so far as is known, a single one taken into a system where it finds congenial soil, may be the cause of virulent disease.

Of course, disease germs, and disagreeable odors arising from certain diseases accompany the presence of sick people whose proper place is in the sick-room or

the hospital, but a perfectly healthy man is constantly vitiating the air. It has in the past been thought that this was due entirely to the CO_2 gas exhaled, and all estimates and designs were made with the idea of removing it alone. Now the best opinion is in favor of the view that the vitiating of air by human beings, so far as it is made unfit for use, is due chiefly to the organic matter given off.

The facts are these: Pure air contains about 4 parts in 10,000 of CO_2, while exhaled breath is burdened with 400 parts in 10,000 of that gas.* The air exhaled is mixed with the surrounding air, so that in a well-ventilated room there will be 6, or possibly 10 parts in 10,000 of CO_2, but in the ordinary class of unventilated buildings the amount of CO_2 in occupied rooms is often 15 or 20 parts in 10,000, and sometimes far more. This CO_2 is a negative gas, odorless, tasteless, and entirely non-poisonous. The aqueous vapor given off is equally harmless in itself. It does not differ in any sense from the water that is always in the atmosphere and is so necessary an ingredient for our comfort. Under usual conditions about five per cent., by volume, of exhaled breath is moisture.

The organic matter thrown off from the healthy body is, like many organic compounds, extremely subtle in its nature. There is no chemical means of analysis known that will define it in its varying composition and determine its amount. The most delicate laboratory test that chemistry can devise will show no quantitative difference in this respect between pure air and the breath that has just left the body. There is a popular test of its presence, however, that is not to be mistaken. The peculiar odor which infests an unventilated room occupied by many people, can be attributed to nothing else than this. The reasonable assumption is, that these organic substances, in the presence of warmth and the moisture of the breath, easily undergo decomposition, and make themselves known by the disagreeable odors of their decay.

* Some experiments made upon London air indicate that the commonly accepted proportion of 4 parts of CO_2 in 10,000 of pure air is too high. 159 tests were made in an open space, at St. Bartholomew's Hospital, in the years 1882 to 1884, that give as an average, leaving out the tests on foggy and misty days, 4.3 in 10,000, the lowest being 3.1 on a fine August day. It was concluded by the experimenters that the proportion for pure country air is probably about 3 in 10,000.

Such are, so far as is definitely known, the constituents given off from the healthy human body to the surrounding air. What are the injurious ones? We know that in an unventilated room, occupied by many people, the air becomes in time unendurable, and even if the case is not so extreme, persons living long in poorly ventilated buildings, where the air is habitually "close" and "stale," are debilitated, and lack the energy of those accustomed to fresh air. This statement needs no proof beyond an appeal to common experience. The moisture given off cannot be injurious. The issue then is narrowed down to the CO_2, and the organic matter. CO_2 in excess may cause injury by occupying the space otherwise taken by the oxygen, which is the vital element of the air on which our blood is fed. If the air is thinned out by CO_2, the blood may be robbed of its required supply of oxygen, and debility result. It seems absurd to suppose that the small increase of even 25 parts in 10,000 of CO_2 would have any such effect, but the human body is a very delicate organization, and it may be that a long continued deprivation of this kind would become observable. It is difficult, however, in the light of numerous experiments, to attribute to the small increase of CO_2 the peculiar and immediate depressing effect of a close, crowded room, which room, moreover, is not necessarily a warm one. The majority of modern hygienists are disposed to consider the organic matter the cause of the bad effects of air vitiated by breathing, and to say that the CO_2 has very little to do with it. This view certainly seems a reasonable one. At all events, it is not the CO_2 which causes the very unpleasant odor of a crowded, unventilated room, and this with most people is a practical and very strong inducement to ventilation. The writer is not competent to say what is the ultimate cause of vitiation of the air by breathing. The evidence appears in favor of laying the charge upon the organic matter, but the proof does not seem positive, that the CO_2 has no effect whatever. It may be that they combine to exert an effect upon the health and comfort of human beings, when allowed to accumulate to any extent in the air inhaled. But this makes no special difference so far as practical ventilation is concerned, for, whichever is the cause,

the removal of one involves the removal of the other, and the practical question is, how much air is necessary, per individual, in order to keep these down to a safe, *i. e.*, a healthy limit?

The answer to this question is the object intended in what follows. But before proceeding further, a sharp distinction must be drawn between what a mere theory would require, and the demand of a theoretical discussion based on the actual conditions of practical ventilation. Some scientists have treated this subject apparently under the supposition that a person inhaled through a tube from one reservoir of fresh air, and exhaled through another tube into another reservoir, the supply and deposit being kept entirely distinct. By this method they get a very small amount as a result. The only case that I am aware of in which the actual bore any resemblance to these assumed conditions, was the somewhat unique one of the shipwrecked mariners of the Thomas Hyke, as related by Mr. Frank Stockton. The fact is that actual ventilation is a process of dilution, the expired breath mingling with the air of the room, and the supply needed must be sufficient to keep the mixture in the room down to a proper standard of purity.

To compare with a standard it is necessary that the amount of CO_2 and organic matter present should be estimated. But the latter cannot be calculated. It, however, bears a direct proportion in amount to the CO_2, for obvious reasons, and the latter, which can be calculated by analysis of the air, is made the basis for estimating the presence of the former. It is a matter of experience by those accustomed to study the subject, that 6 to possibly 8 parts of CO_2 in 10,000 of air in a space occupied by healthy people accompanies an atmosphere that has no disagreeable odor, and can be considered healthful. If the proportion rises to 10 or 12 in 10,000 a slight unpleasantness usually manifests itself, and the ventilation cannot be considered thorough. Above that proportion of CO_2, the air soon becomes from breathing absolutely unfit for use. Having this standard fixed it is a comparatively easy matter to determine on the amount of air supply, for, knowing the amount of CO_2 in pure air, the amount in exhaled breath, and the amount of air passing through the lungs in a given time, a simple use of mathematics shows the amount of fresh air required per hour to dilute the breath and bring the mixture to the required standard. It is simply then a matter of the standard taken that varies the air allowance. Dr. Parks, who is one of the highest authorities, places it at 6 in 10,000, which requires a supply of 4,000 cubic feet per hour per person. The late Mr. Briggs adopted 8 in 10,000 as a standard, which requires a supply of 1,800 cubic feet per hour. M. Planat appears to consider 10 parts in 10,000 a sufficiently high standard.

It may seem that these wide differences destroy all value of calculations, but it should be remembered that the test by CO_2, while in a sense indirect, is yet a very delicate one, that a very slight difference in amount of CO_2 will accompany a decided change in the comfort and health of the air. If we are content with a somewhat tainted air, a standard of 10 in 10,000 will answer, and we will, so far as the air is concerned, probably live to a good old age. If we want air in our rooms, entirely free from traces of mustiness, and as fresh to our senses as that which blows over the mountains, we must take Dr. Park's estimate. The expense may in some cases prohibit such a standard being attained, but, as he writes with reference to another matter, "After all, the question is not what is likely to be done, but what ought to be done, and it is an encouraging fact, that in most things in this world, when a right course is recognized, it is somehow or other eventually carried out." Dr. Parks gives as a rule easy to be remembered, one cubic foot per person per second, equal to 3,600 cubic feet per hour.

Most writers make a distinction as regards age and sex of the people, and also regarding their occupations. In view of the considerable difficulty of obtaining exact amounts in ventilation, it seems an unnecessary refinement to allow a deduction from the above standards for adult males, even in the case of children, for as Dr. Billings observes, the latter are more delicate and susceptible to impure air.

For difference of occupation the case is different, as some kinds of work increase vastly the energy of breathing.

If some one exclaims in impatience, these standard amounts are very fine, but

entirely impracticable on account of expense, let him remember that to get ventilation he must pay for it. If he wants the best ventilation the highest standard is not too high. The entire matter is one of compromise between good air and expense. As a reasonable compromise in many cases the 1800 cubic feet allowonce may be used, but any lower allowonce than that for largely occupied rooms should not be allowed.

So much for the vitiation caused by the persons of human beings. The special sources of vitiation of air may now be briefly considered. It will be recalled that the term *special* is used to denote the causes of vitiation met with in buildings, other than the human beings occupying them. It would be more general to say, other than the living creatures occupying them, for in the case of stables and the like it is a highly important duty of the sanitary engineer to ventilate them and base his calculations on the number of animals present. The chief distinction between the animate and the special sources of vitiation is, that the former are continually in operation, and with some degree of regularity, while the latter are varying, both in degree and continuity. There is another important difference in respect to treatment. The animate sources of vitiation must be allowed to breath into the surrounding space, and their vitiation be mingled with the air of the rooms, whereas, in nearly all cases, the special impurities can be directly conveyed away.

The usual special causes have been enumerated. Some of them, such as gases from poor furnaces, etc., are hardly legitimate, but nevertheless do occur. No calculation can be made for them. The gases and mechanical particles arising from manufacturing operations are so various in nature and amount that no general allowance can be made for them. As a rule they should be immediately and thoroughly removed from the work-room.

Likewise, for the odors arising from numerous domestic operations, no allowance of air can be given for their dilution. It would require all out-doors to make the odors of wash-day unobservable.

The only effectual plan is to carry off such sources of unpleasantness as soon as possible.

The subject of illumination is one that comes under this heading. All do not realize what consumers of air our lamps and gas lights are. From one point of view they are necessary nuisances. In the operation of burning large amounts of CO_2 are given off, and also other products more or less injurious and disagreeable. The heat evolved is a separate matter, entirely apart from the effect on the purity of the air. Experiments show that a candle gives about 0.3 cubic foot of CO_2 per hour, an ordinary lamp about 1 cu. ft. per hour, and an average of tests made by Mr. H. C. Bowen, of New York coal gases, both rich and poor in hydrocarbons, give 0.75 cubic foot of CO_2 per cubic foot of gas burnt. A 4½-foot burner yields then, 3.38 cubic feet of CO_2 per hour. An adult in ordinary conditions of quiet occupation emits about 0.6 cubic foot of CO_2 per hour. So, as producers of CO_2, a man equals two candles, a lamp equals two men, and an ordinary gas-burner can hold its own against nearly six men.

It cannot be claimed positively that the production of CO_2 by lights represents the same corresponding vitiation of the air for breathing purposes, as in the case of man, for organic matter is not proportionally evolved. But, especially in the case of gas, there are other products given off, quite as objectionable in their nature. Anyone who has had occasion to mount a step-ladder in a close room, brilliantly lighted, can bear testimony to the overpowering and peculiar condition and odor of the air near the ceiling, a condition that heat alone could not occasion. More or less free gas escapes unconsumed, and some of the carbon is burned only to carbonic oxide, a very poisonous gas. Also, the gas is very liable to emit di-oxide of sulphur if the coal contained any of that impurity, which enters the lungs and there forms sulphurous acid, injurious in its effects. There are other products of combustion which a gas analyst can better describe, but enough has been said to show that the amount of vitiation increases directly as the amount of CO_2, and hence, if the products of combustion are allowed to mingle in the room, the same test of the purity of the air can be applied as for man.

The question then becomes as before, what standard for the allowable amount of CO_2 should be taken? Wolpert, says that the air supply should be 1,800 cubic feet of air per cubic foot of gas burnt. A calculation shows that this corresponds to a standard of 8 parts of CO_2 in 10,000. Briggs, who we may be sure would give full prominence to the economical side of the subject, gives this rule for halls of audience: "Ten cubic feet of air per minute per cubic foot of gas burnt per hour." Hence, for a 4½-foot burner, 2,700 cubic feet of air per hour. This makes the standard of CO_2 16 parts in 10,000 of air. Dr. Parks approves the larger estimate, and it seems the best standard, although there may be modifying causes in some cases that will make Mr. Briggs' rule advisable.

The preceding remarks are based on the assumption that the products of illumination are to be allowed to mingle with the air in the apartments lighted.

In the case of candles and movable lamps such a course is advisable, but for gas lights it is a question if the evolved gases should not be directly carried away. Or rather, there is no question at all of the propriety of doing so in all cases where arrangements can be made for what is termed exclusive lighting.

This concludes the attempt to indicate the steps by which the foremost sanitarians of the present day have reached their conclusions regarding amounts of air supply.

As was stated before, the apology for devoting space to this subject lies in the desire to leave no room for the opinion that the demands of science in this respect are the demands of hobby riders, or of those who theorize, with supreme indifference as to whether the conditions they assume are ever met in practice or not.

The figures given are as definite as is the price of gold, quoted at the mint, and as practical as the current quotations of iron. The standard of purity can be varied, to be sure, but if lowered to reduce expense the purity of the air is likewise lowered.

The effectiveness of ventilation and the cost of ventilation are, within limits, in direct ratio to each other. When we are told that to keep the standard of purity at 6 parts of CO_2 in 10,000, the supply must be 4,000 cubic feet per hour, this means that if a man is put in an absolutely tight room of 4,000 cubic feet capacity filled with fresh air, at the end of one hour the air will have reached the limit of impurity, and after that it will become unhealthy, according to that standard. Similarly for a gas light.

There is no room for uncertainty in these figures; they are as precise and practical as any of the data on which business calculations are based. It is merely a question of how pure you intend to have the air.

These data are precise, and as such are the only fit basis for calculations, but at the same time, in their actual application they must be frequently modified, as I will endeavor to explain. As in all applications of scientific truth to practical necessities, it is necessary to remember that a perfect theory cannot take account in a single formula of all possible conditions that may be met with in practice. It can only serve as a foundation for estimates made to suit the special cases that continually arise. Skill and common sense are necessary to decide how far the conditions of the case should influence the amount demanded by the special conditions used in deducing the theoretical supply. This is the only sensible; it is the only scientific way, and it accounts for the apparently wide separation between the theoretical amounts specified by sanitarians, and the actual amounts required by the best sanitary engineers for different kinds of buildings.

With this sound basis to build upon, the next step in order is to touch upon the main points influencing the selection of an amount of air supply, and then to give the amounts used by engineers for various buildings.

Perhaps the first practical condition to be mentioned that differs from those assumed in estimating the standard air supply, is what may be termed insensible ventilation. It is mentioned first because always existing. The conditions of the theory suppose a man inclosed in a room absolutely impenetrable by air, except through certain definite channels under control. The fact is, this never exists. Movement of air constantly takes place

through window cracks, etc., and even through brick walls. Mr. G. P. Putnam mentions in "The Open Fireplace," experiments he made with a room in which every observable crack and opening was carefully puttied, the brick chimney-back and jambs were oiled, and ultimately four coats of oil paint put on the walls and ceiling, and three on the pine floor, but after all this the inflow from the furnace register was only diminished 20 per cent. At the end of the hour a quantity of air more than equal to the entire capacity of the room had passed through the register. There were, of course, microscopic outlets for the air which it might be possible to close, but this illustrates the fact that the inlet and outlet registers of a room are by no means the only modes of passage of the air.

The importance of insensible ventilation does not lie in its being a condition to be calculated upon in arranging a systematic scheme of ventilation, for in such cases the regular, legitimate air supply is the only one to be relied upon; but it lies in the fact that without it, nine-tenths of civilized humanity would long since have had, like the colored gentleman, "to take to the woods."

In the light of what has been mentioned before it needs no demonstration that in unventilated buildings, if it were not for this insensible ventilation, people could not exist. It is the salvation of thousands of families in elegant homes, and even it does not in many cases prevent premature loss of health, and even death from slow suffocation.

Insensible ventilation is, however, a factor that the architect can very reasonably take account of in designing many houses where the number of inmates is small and the expense must be a minimum.

Cubic space allowance is another condition of the air amount question that is well worth considering. Its position as an element of the problem is very easily defined, although more or less misconception of it exists. If a certain number of people occupy a given room, each person has a certain number of cubic feet of space in that room, that for purposes of estimate may be called his. The simple question is, how does it affect the air supply required by him?

There is, unquestionably, an impression among many that cubic space takes the place of ventilation.

To a limited extent this is true; that is, apparently true; for if you place a few people in a sufficiently large room, with no means of ventilation, the air may still keep passably pure owing to insensible ventilation, and roughly speaking, the degree of purity will depend on the cubic space allowance. Those few inmates may occupy that room continuously and breathe good air. But if a large number of people occupy the room, the insensible ventilation is entirely inadequate, and the air becomes very bad. The space allowance cannot then, in any sense, take the place of air supply. It merely serves as a mixing chamber for diluting the persons' breath with fresh air. Each person should have so many cubic feet of fresh air per hour, independent, within limits, of how large a space that air flows through. But, indirectly, the space allowance may influence the air allowance in this way. If, previously to its occupation, the space is filled with fresh air, it acts as a reservoir, upon which the lungs can draw until it has reached the limit of impurity set by the standard taken. As soon as this limit is reached, however, then the regular air supply must go on entirely independent of the cubic space.

This is theory, but it is theory to which practice makes the closest of approximations in cases of crowded rooms, and can only be disregarded where the active sources of vitiation of the air bear only a small proportion to the insensible ventilation.

It is apparent, then, that when rooms are occupied for short sessions, and between sessions the air is thoroughly renewed, it is perfectly allowable to reduce the air supply in just so far as the space serves as a reservoir. When rooms are continuously occupied by many people, the amount of cubic space cannot lessen the required air supply.

In the case of rooms large relatively to the number of inmates, or other source of vitiation, cubic space allowance may very reasonably materially affect the allowance of air supply, and in some cases may be rightly assumed to take the place entirely of systematic ventilation, especially where the expense must be kept down to the lowest limit. It is on such

grounds as these that the specification of cubic space allowance for tenement houses and some other buildings can be justified. The specification of it for schools, with the idea of its taking the place of systematic ventilation, ought not to be tolerated. If any room needs ventilation it is the schoolroom.

While considering the practical conditions that affect the selection of a standard of air supply, the relations of warming and ventilation may well be discussed. Theoretically they are distinct subjects. Ventilation is, for hygienic reasons, a necessity. Warming is, within limits, merely a matter of convenience and pleasure. A great part of the time we warm our houses to be comfortable, not because it is necessary for health. If we wore warmer clothing we might live in much colder houses in good health. The physical condition of many who live in hot, stuffy rooms would probably be improved by such a course of treatment. Of course this supposes dampness to be eliminated.

Theoretically, then, ventilation is necessary at all times, and in amounts independent of the temperature, while warming is a matter dependent upon the climate and the "cold waves" that the Weather Bureau sends us. The Arab in his tent, and the Esquimaux in his reeking snow hut, both require fresh air.

Practically, however, warming and ventilation are very closely connected especially in this climate of cold winters. The reason lies in the fact, that in order to make a building comfortable in this climate in cold days, and with a reasonable expense, it is necessary to heat the air itself. Hence, the greater the amount of ventilation, the greater the amount of heat required, and the expense. It may be laid down as a practical truth beyond peradventure, that people will insist on being warm in preference to being well ventilated If one or the other must be sacrificed, it will be the ventilation, every time.

If the expense of sufficiently warming the volume of air required for good ventilation seems excessive, the householder will in all probability cut down the air supply. He is hardly to be blamed for this. The most rigid sanitarian will shut the window if he is chilly, although he knows it to be the only inlet for fresh air to the room.

This matter of the relation of warming and ventilation is seen to be one of dollars and cents, rather than of physical science, and hence its influence in determining the amount of air supply is of a different nature from that of cubic space allowance. As a sanitarian, no architect or engineer ought to consider it. As a practical business man, he has to consider it, and should always remember that, as regards the popular use of the title "warming and ventilation," there is a significance in the order of the words.

For many public buildings, however, such as hospitals and schools, no consideration of the expense of warming should move the designer from rquiring a sufficient air supply.

The natural ventilation, cubic space allowance, and the relation between ventilation and warming are the chief matters influencing the reduction of air supply allowance that are not directly connected with the inmates and their occupations. In special cases of manufacturing buildings, etc., there are special causes of vitiation; but, as has been said, these should be carried off directly where practicable, and in that event do not influence the amount of air supply required for the inmates.

The occupations and physical conditions of the inmates of buildings, of course, have a bearing upon the amount of air supply, but are directly connected with the inmates themselves. The best way of considering them is to pass directly to the amounts of air supply selected by engineers for various kinds of buildings. The chief factors in causing the varying figures for different buildings have been—First, the length of time that the rooms were used continuously; second, the physical condition and occupations of the inmates; and, third, but perhaps more potent than all the others, the amount that it is reasonable to expend for ventilation on different building.

The highest figures used are for hospitals. Nothing less than the highest standard already given ought to be taken for such buildings. Dr. Parks has had great experience with hospitals, and he states that the minimum for them ought to exceed the allowance for healthy be-

ings by at least one-fourth. In wards for surgical operations a much larger allowance should be made. Four thousand to five thousand cubic feet per hour per person is required by Péclet. Planat states an amount in cubic meters which equals 5,300 cubic feet. Hospitals for diseases, in which there are very offensive exhalations from the body, and especially for contagious diseases, require practically all the air that can be obtained. The supply should not be less than 7,000 cubic feet per hour. In the case of hospitals the necessity for fresh air is so apparent that there is comparatively little difficulty in persuading people to meet the expense of this thorough ventilation.

For theaters, those engineers who are strong upholders of the higher standards of purity of air require 2,000 to 2,500 cubic feet per hour. In this reduction from 3,600 cubic feet, they doubtless consider that the use of the theater is not continuous, and that the upward movement being a prominent feature of theater ventilation, the breath is more rapidly removed from the level of the audience.

Most engineers adopt figures that are more of a compromise with expense. General Morin requires 1,400 to 1,800 cubic feet per hour. This estimate, although much smaller than the first, will give very fair ventilation. Compared with those theaters which have no thorough system of ventilation, it seems all that could be desired. The Madison Square Theater, of New York, has a theoretical supply of 1,500 cubic feet per person, and is very successful in its ventilation. The Vienna Opera House, which is considered one of the very few well-ventilated theaters, has a theoretical supply of about 1,000 cubic feet per person.

The conditions of church ventilation are in many respects similar to those for theaters, and about the same air allowance should be made. In the majority of churches the services are not attended by crowded congregations, and hence tolerable ventilation may be obtained with much less air supply, but special occasions frequently occur when the ventilating apparatus is taxed to its utmost. Considering this, it is unadvisable to make any less allowance for churches than for theaters.

Rooms used for lectures, etc., of an hour or so duration, require much the same air supply as for theaters, if the ventilation is arranged in the same way as is usual for the latter class of buildings.

All lecture rooms with low ceilings, where the exhalations from the body are more mingled with the air about the inmates than is the case in theaters with good upward ventilation, require a larger allowance. For thoroughly satisfactory results, the full air supply required by the standard taken will be necessary. If exclusive lighting is not practiced, there should be a liberal allowance for the use of the gas-burners, according to the figures already given. Mr. Briggs, in his paper on "Halls of Audience," takes a position on the verge of robbing the ventilation to propitiate the pocket. He writes—"Dr. Reid's value of 10 cubic feet per minute is all that should be used in planning for halls not occupied over two or three hours at a time. All that can be judiciously urged for ventilation in view of the cost of fuel." He states further to the effect that this is the minimum allowance, and that the apparatus should be designed so that during warm weather the supply can be increased to 20 cubic feet per minute. "An amount which, with open doors and windows, if ventilating currents are well distributed among the audience, will be ample for the comfort of a crowd in hot weather." These are the views of a practical and experienced engineer, and as such are of value, but nevertheless the testimony of others, and the results obtained with designs in operation, lead to the belief that they go too far in compromising the ventilation.

It is certain that, in the case of small and crowded lecture rooms, 600 cubic feet per hour per individual will not prevent impurity of the air.

Court-rooms, legislative halls, and all that class of rooms that are liable to continued occupation for many hours by a crowded congregation, require an ample supply of air. Nothing less than the full amount corresponding to the standard of purity selected should satisfy the designer. Dr. Reid, in his writings on the ventilation of the Houses of Parliament, shows the importance of keeping the brains of the law makers clear and

active, and if that is necessary in England, it is quite as much so for our own State and National Legislators, and for the typical American jury. Gen. Morin, who bases his figures on a theoretical supply of 1,800 cubic feet per person per hour, irrespective of conditions, and then modifies this amount for different cases, requires for "lecture rooms and halls for brief receptions" 1,100 cubic feet, and "for assembly rooms and halls for long receptions," 2,100 cubic feet per hour, a difference of nearly 100 per cent. in favor of the latter. In public buildings, like court-houses, State capitols, etc., there is no excuse for not supplying a generous air allowance. The money question should not prevent the best ventilation.

The opinions of engineers as to the air supply for schools are various—from those who would limit small children to 200 cubic feet per hour, or even less, to those that approve of supplying to them the same amount as for adults in crowded rooms long occupied. It is hardly necessary to allude to the importance of well ventilating schools. The miserable condition of many of our schoolrooms in this respect may have no small effect upon the health of a generation, upon which, in fifteen or twenty years, the prosperity of the country will depend.

From considerations already alluded to, it seems unadvisable to reduce the supply because of the youth of the children. Of course, in the case of schoolrooms that are to have few scholars in proportion to their size, a small air allowance may be admissible, but this is more because of natural ventilation taking place than from the age of the inmates. Nearly all schoolrooms will be crowded at times, and that for hours together, and for them the full air allowance should be made. For those rooms that are occupied only an hour at a time, and at the end of the session are completely flushed by fresh air by opening the windows, it is allowable, perhaps, to make some reduction in air supply, because of the space acting as a reservoir. But this latitude should not be imposed upon. A well-filled room with low ceiling will soon become close unless ventilated. If the air allowance is too much reduced, the room will become close and unhealthy before the close of the hour. If the air is to be maintained rigidly up to a standard of purity, little, if any, reduction of supply can be made for well-filled rooms, although they are flushed every hour.

A few years ago a commission was appointed to examine the public schools of the District of Columbia, and in their reports, dated March 15, 1882, appear the following specifications:

"In each class-room not less than 15 square feet of floor shall be allotted to each pupil. In each class-room the window space should be not less than one-fourth of the floor space, and the distance of the desk most remote from the window should not be more than one and a-half times the height of the top of the window from the floor. The height of the class-room should never exceed 14 feet. The provisions for ventilation should be such as to provide for each person in a class-room not less than 30 cubic feet of fresh air per minute, which amount must be introduced and thoroughly distributed without creating unpleasant draughts, or causing any two parts of the room to differ in temperature more than 2° F., or the maximum temperature to exceed 70° F."

The list of buildings of various kinds for which ventilation is necessary is by no means exhausted, but the above are the chief among what may be termed public buildings. Hotels, office buildings, banks, prisons, etc., all offer conditions that must be considered, according to the same principles as the foregoing examples.

There are a great variety of buildings devoted to special trades and manufactures, for which special allowances must be made. The impurities, both mechanical and chemical, given off in various processes of manufacture, should, if possible, be immediately carried away at their source; but this cannot always be done, and then a large supply of fresh air is required to sufficiently dilute them and keep the air of the room in a healthy condition for the workmen. The accurate estimate of the supply needed in such cases is a very difficult, if not impossible problem. It is almost entirely a matter of experience and judgment, although it must be admitted that the amount of available experience in the subject is very small. The amount of air supply may be based upon the number of

people present, and an extra allowance made per person over what would be required if they were the only sources of vitiation, this extra amount to be determined by experience; or, an extra allowance may be made in bulk for all the special sources of impurity independent of the number of workmen present. An illustration of the former method is given in the design for the ventilation of the laboratories of the Massachusetts Institute of Technology, described in the "Sanitary Engineer," of October 30, 1884:

"For recitation rooms and lecture rooms 1,500 cubic feet per hour are allowed to each occupant. For physical laboratories, where the gaseous products of bunsen flames and electric batteries are likely to act as vitiating agents, 2,000 cubic feet per hour are allowed. For chemical laboratories, which are supposed to be supplied with effective hoods for the collection and removal of offensive or dangerous gases and fumes, and also under which any work evolving a considerable quantity of gas is supposed to be done, 3,000 cubic feet; and for the organic chemical laboratory, 4,500 cubic feet are allowed to each occupant per hour. To other rooms of the chemical floor, as the library, balance room and volumetric room, 2,000 cubic feet was apportioned to the individual, because of the proximity of chemical laboratories, and the desirability of being able to produce within them an excess of pressure, causing outward air movement."

With regard to the supply of 1,500 cubic feet in lecture rooms, it may be well to quote further—

"Good ventilation based on so low an estimate as 1,500 cubic feet per occupant would not be possible in most climates, and in the comparatively dry climate of New England that allowance makes the most efficient and economical use of the supply a necessity."

The reason for the distinction made between moist and dry climates, is that the impurities would not be so disagreeable, because less noticeable, in the latter, although with a given air supply they would exist the same in both cases. It seems a little unfortunate to make this distinction, when the avowed purpose of ventilation is not merely to obtain what is agreeable, but to go a step beyond, and attain to what is an absolutely healthy supply. If this is done there can hardly be any practical distinction for moist and dry climates. But the opinion is evident in the quotation, that a supply of 1,500 cubic feet per hour for each person is little enough for the lecture rooms of a college.

There is a class of buildings that has not yet been alluded to, and these may best be described as private buildings. Dwelling-houses are seldom mentioned in discussions of the air allowance for buildings, probably for the reason that a systematic air allowance is seldom, if ever, made for them. Nor is one always needed. This statement can be maintained on strictly scientific grounds, even in the face of the fact that ventilation or change of air is always necessary where human beings are present. The preceding analysis of the conditions influencing the amounts required in ventilation places us in a position to do so.

In addition to the all-important item—expense—natural ventilation and cubic space allowance both have a very great influence upon the ventilation of dwellings; so great, as in many cases to make systematic ventilation practically unnecessary. In many cases, but decidedly not in all. Dwellings differ largely in their requirements for ventilation, and judgment should be exercised in deciding when a thorough ventilating design is necessary, and when a reasonably healthy atmosphere can be maintained without it, or with only a few simple devices for the circulation of air. The lines on which such a judgment is based appear to be about as follows:

If there is any building for which regard must be had to the expense of ventilation, it is the dwelling. Public buildings are usually constructed by governments, corporations, or wealthy individuals, and the expense of a thorough system of ventilation is very small in comparison to the cost of the building, and, considering the importance of the matter, should be cheerfully met. Not so with the usual private house. It is built for the man who is toiling over a city desk, or with his hands, day after day to provide food for his family, and from the first foundation stone, to the setting of the chimney cap, the cost is never lost

sight of. For such buildings, the expense of ventilation must be brought down to the lowest practicable limit, or it will be entirely debarred. For private dwellings, in particular, elaborate schemes of ventilation are a failure, because too costly. Happily it is possible to obtain a fair amount of ventilation in many cases with very little outlay, either in first cost or in running expenses.

The usual home is large in proportion to the number of people it covers. Unlike the theatre or the concert hall, where the audience is closely packed, the sleeping room has rarely more than two in it, and even the family sitting-room in modern times does not generally contain over five or six persons. The proportion of cubic space in private rooms is usually quite generous to each person, and although any amount of cubic space does not in itself take the place of ventilation, yet this gives a better opportunity for natural ventilation to change the air than if the people were closely crowded. Natural ventilation is, as a rule, far more active in houses than in public buildings, and it may even become an efficient means of ventilation in some cases. The wall and window surface per individual is large in private rooms, and the natural ventilation is consequently greater.

Houses are generally constructed more lightly than larger buildings, and, especially with frame buildings, there is every opportunity for very active natural ventilation. I have sat in country rooms with the outside temperature well down toward zero and seen the carpet rise and fall with each wintry gust, as it forced its way under the floor. Such a house must surely be well ventilated, at least while the wind blows. It is, perhaps, one redeeming feature of what are expressively termed "skin" builders, that the houses they construct give every chance for natural ventilation. Speculation brown-stone fronts, put up a row at a time, are very expensive to warm, for this reason, but they are sometimes better ventilated than the more carefully-constructed building beside them, that the retired merchant has taken pride in erecting.

Natural ventilation, then, can be largely calculated upon to change the air in private houses, and, while it cannot be claimed to be always sufficient, yet there are many cases where more is hardly required. During the summer the windows are open most of the time. During the winter, the furnace, if properly designed and set, will supply sufficient fresh air for the inmates, not to speak of the circulation that is constantly going on through cracks and ill-fitting windows. Open fires, if used in addition to the furnace —would that they were more so—quite efficiently ventilate the rooms they are in.

Where close stoves are used, little can be claimed for them as ventilating agents, and it is undeniable that, even in country houses, rooms are sometimes met with that are as close as the stoves themselves.

More often, however, the natural circulation keeps the air in a tolerable condition, and a few simple devices will much improve the ventilation of stove-heated rooms. At all events, a systematic supply and removal of air, involving continual expense, is out of the question in the great majority of dwellings, so long as experience shows that they are habitable without it. Resource must be had to simple and cheap means of aiding the natural ventilation in its good offices.

The opportunity is tempting, here, of digressing into a discussion of the ways in which a fair ventilation can be cheaply obtained in houses by the use of the appliances for warming, and also of the various means of warming houses, but the aim of this paper is not to describe how to ventilate, but how much to ventilate. In this direction enough has been said to substantiate the statement, that, for the ordinary private house, a systematic air allowance per individual is almost an absurdity, and that for many of them a thorough systematic plan of ventilation is unnecessary, even were it not debarred by reason of the expense inseparable from it.

The only dwellings for which such a plan of ventilation is not out of the question are those inhabited by the wealthier classes. Houses for which a large sum has been paid at the start, and whose yearly expenses are so considerable as to make the cost of running the ventilation merely an item in the total amount.

Steam heating, by indirect radiation, is becoming quite common in this class of buildings, and the very fact of properly

warming by this method involves the flow of large volumes of air into the rooms. The same condition should accompany the use of furnaces, and would, if they were made warm-air furnaces instead of hot-air furnaces, as they are only too justly named.

By the use of outlet flues, properly heated, the air is forced out of the rooms, and excellent ventilation obtained. Ventilation can be maintained when it is too cold to have open windows, and yet too warm for using the heating apparatus, by heating the aspirating shaft or flues. But, even for these houses, it is easily seen that a systematic air allowance of so many cubic feet per hour for each individual is hardly necessary. For rooms to be occupied by dinner parties, or crowded during social gatherings, such calculations are advisable; not so for the ordinary household rooms. The fact is, that, as warming apparatus is now set up, the amount of air entering these rooms depends not on the number of people using them, but on the number of square feet of radiating surface that experience shows is necessary to warm them, and the amount of air that will flow over this. With the exception of the special rooms mentioned, this will practically give all the ventilation needed, at least during cold weather. For warmer weather, some way of exhausting the air must be provided.

Of course, where gas is used for illumination, some means of specially ventilating it should be used, or else rooms not supplied with systematic ventilation will become unhealthy during the evening. There are inexpensive ways of ventilating gas lights that should not be omitted in modern houses. But even if this is not done, and the absence of gas-light ventilation makes systematic ventilation more necessary, the point is that it is for a special source of vitiation, entirely independent of the number of inmates of the room.

The endeavor has been in the preceding remarks concerning the ventilation of dwelling-houses, to maintain the position taken at first, that, having full regard for the hygienic condition of our homes, admitting that human beings require a certain amount of fresh air every hour, yet a systematic air allowance based on the number of people present is not the necessary or the best way of treating the subject for houses, as it is for most public buildings. Rooms for entertainments, which are at times decidedly public rather than private in their use, are excepted.

This may not be admitted by all, and yet the amount of air supply, even in cases where a systematic ventilation is planned for houses, is and will be decided by certain practical considerations, that will give just as efficient ventilation as if something like the following course had been pursued:

That room will hold three or four people, and must have so many cubic feet of air per minute. This bedroom will accommodate two, and must have so much. Only the cook stays in the kitchen, we will give it half as much as the bedroom. Nobody lives in the hallway, so there can be no need of ventilating it at all.

CONTRIBUTIONS TO THE STUDY OF ANTISEPTICS.

By F. Boillat.

From "Journal für Praktische Chemie," for Transactions of Institution of Civil Engineers.

THE researches recorded in this paper were undertaken on account of the appearance of a pamphlet on disinfection by Dr. R. Koch. Koch states therein that of the substances at present employed as antiseptics, the only ones worthy of the name are chlorine, bromine, iodine, corrosive sublimate, with possibly potassium permanganate and osmic acid. This contradiction of generally-accepted facts is not, however, considered as strong as it appears. In medicine, and more especially in surgery, it is sufficient if the antiseptic employed is capable of preventing the formation of micro-organisms which are detected by examining the wound and its secreted matter under the microscope, and if the propagation of organ-

isms is arrested for a time long enough to allow the wound to heal, the antiseptic has fulfilled all its requirements. It has, however, never been determined why, by the use of a particular antiseptic, putrefaction and the development of micro-organisms is prevented, and it has been supposed in general that the substance destroys germs or arrests their propagation. It is evident, however, that substances such as phenol, chloride of zinc, acids, corrosive sublimate, ethereal oils, &c., all of which differ in chemical constitution, cannot possibly act on the vitality and development of bacteria in the same destructive manner. Moreover, a number of these micro-organisms, *e. g.*, the splenetic fever germs, form spores which, as may be expected, resist the action of antiseptics very powerfully. As soon as inquiries are made into the injurious effects of antiseptics on the development and vitality of organisms and their spores, it immediately becomes necessary to subject antiseptic agents to a proper classification. Koch, who has investigated the action of various antiseptics on definite species—*Monas prodigiosa* and *Bacillus anthracis*—by allowing the micro-organisms under examination to remain in the antiseptic medium for a longer or shorter period, and subsequently introducing them into a suitable nutritive solution, and regarding the appearance or non-appearance of their development and propagation as a criterion of their vitality, must necessarily have arrived at a different opinion with regard to the efficacy of many antiseptic substances. On reading through his work, however, one readily conceives that even his mode of judging the value of an antiseptic is one-sided. For instance, the spores of the splenetic fever organism, after being preserved for many days in a 1-per-cent. aqueous solution of phenol, or in a 5 per-cent. solution of calcium chloride, do not lose their capability of development; their propagation is, however, arrested, and this is of great importance for medical purposes; for although substances like chlorine, bromine, acids, &c., would effectually destroy bacteria and their spores, they would in most cases, when applied in the same, or even in less concentration, destroy the tissues of animal organisms. The application of such substances for the treatment of wounds is therefore not practicable. Until it is possible to find a specific poison for germs which will not injure the human organism, the antiseptics employed for the treatment of wounds will be those which are more or less injurious to the animal tissues, but severely injure the vitality micro-organisms, *i. e.*, arrest their development. The use of destructive disinfectants, such as alkaline solutions, &c., is adapted only, and that to a limited extent, to the preservation of lifeless objects. This explains why, *e. g.*, chloride of zinc, although it does not kill the spores of the splenetic-fever germs in a 5-per-cent. solution, is nevertheless a good antiseptic agent. Koch erroneously asserts that chloride of zinc does not possess the property of arresting the development of bacteria.

Most antiseptics are characterized by the circumstance that they coagulate dissolved albumen, forming permanent insoluble compounds therewith. On treating blood serum or egg albumen with a dilute solution of sulphate or chloride of zinc, Lieberkühn's zinc albuminate having the composition $C_{72}H_{112}N_{18}SO_{22}+ZnO_2H_2$, and containing 4.74 per cent. zinc, is formed, a similar reaction occurs when the wound is treated with the solution of a metallic salt. That chloride of zinc, corrosive sublimate, chloride of iron, &c., do not remain as such on the surface of the wound, but combine with the albumen of the tissues, there is no longer a doubt. In order to determine how far these metallic salts, when placed on wounds or brought into contact with albumen, act as antiseptics, it is necessary to investigate the behavior of micro-organisms on such albuminous metallic precipitates. Such experiments have, to my knowledge never been made, and at the suggestion of Professor Nencki I have undertaken this work in the interest of a rational study of antiseptics.

Samples of blood serum and egg albumen, the latter diluted with three or four times its weight of water were treated with an excess of solutions of phenol, chloride of zinc, sulphate of copper, and corrosive sublimate, and the resulting precipitates washed on filters until the wash water was free from the precipitant; 2 or 3 grains of the moist precipitate was then made up with water to a thin paste, and allowed to remain at the

ordinary temperature, loosely covered with bell-glass. Watch-glasses, containing fresh blood serum and Koch's nutritive gelatine, served to control the experiment. The results of these experiments are shown in the following table:

Albuminates.	Time after which the first Micro-organisms were observed. In Days.	Time after which putrefaction and bad smell were observed.	Remarks.
1. Serum	1	2	After the fourth day fungi appeared, which grew rapidly, covering the whole substance after ten days.
2. Nutritive gelatine	1	4	
3. Phenol albumen serum	2	6	
4. Phenol albumen (white of egg)	2	6	
5. Copper albumen	28	40	After forty-six days the substance which had been light blue, changed and gave up the blue to the water. After thirty-one days fungi appeared which covered the whole of the substance in fifty-four days.
6. Zinc albuminate serum	31	46	After fifty-four days the substance assumed a dark color and strongly putrid smell.
7. Zinc albuminate (white of egg)	31	46	Ditto.
8. Mercury albumen serum	42	60	No fungoid growth.
9. Mercury albumen (white of egg)	45	60	Ditto.

In a second series of trials the same metallic albuminates (prepared from blood serum) were sown with a green coccus found on an infusion of coffee. It consisted of cocci of an average diameter of 1.0 micro-millimeter, partly isolated, and partly joined together in masses:

Albuminates.	Time after which the sown Fungus showed a distinct increase. In days.	Remarks.
1. Nutritive gelatine	2	
2. Copper albumen	No growth	Even after the lapse of four weeks it was not possible to detect, either mucroscopically or microscopically an increase of the inocculated places.
3. Zinc albuminate	"	
4. Mercury albumen	"	

In a third series of experiments splenetic-fever germs were dried on silk threads and brought into contact with the metallic albuminates.

Albuminates.	Time at which the Spores of splenetic-fever germs grew to threads. In Days.	Remarks.
1. Nutritive gelatine	1	
2. Copper albumen	No growth	Even after four weeks no growth of the spores was observable.
3. Zinc albuminate	"	
4. Mercury albumen	"	

The same experiment was repeated with splenetic fever bacilli. The latter rapidly shot out of the nutritive gelatine in threads, which contained spores, within the space of from three to four days. On the metallic albuminates, however, it was impossible to observe growth of any kind. From these experiments the following conclusions may be drawn:

1. The substances serving to control the first series of experiments exhibited fungoid growth in twenty-four hours, and showed distinct signs of putrefaction in from two to four days. The green micro-cocci, sown with nutritive gelatine, in the second series of trials increased perceptibly in two days, whilst the spores in the control substances of the third series of experiments had grown into threads.

2. The albumen precipitated by phenol, and subsequently washed, became putrid in the first series of experiments in forty-eight hours. This coincidence, remarkable on account of the permanency of the metallic albuminates, is explained in a simple manner. The coagulum of albumen produced by carbolic acid, when washed completely with water, was perfectly odorless, and on heating a large quantity of it with dilute sulphuric acid in a retort, to the boiling point, the distillate was perfectly free from phenol when tested with bromine. It is possible, therefore, to completely wash out the phenol from the phenol albumen precipitate, and this explains why the phenol albumen, like the substances used to control the experiment had become putrid.

3. The copper, zinc, and mercury albuminates proved to be unfavorable nutritive agents for micro-organisms. They would probably resist putrefaction for an unlimited period if they were not exposed to the action of atmospheric oxygen and water, by which action they appear to undergo gradual decomposition. It is an interesting fact that the antiseptic action of the inorganic metallic salts is the same as that of the corresponding albumen compounds. Mercuric chloride being the most powerful antiseptic, albuminate of mercury also resists putrefaction for the longest period.

My experiments explain the differences of opinion which exist between the statements of those authors who consider chloride of zinc a valuable antiseptic and the experiments of Koch, according to which, he fails to realize why chloride of zinc has ever received the name of a disinfectant. The metallic salts, when introduced into albuminous nutritive solutions or placed on wounds, immediately produce metallic albuminates, which compounds, although *per se* not poisons for germs, are no longer suitable for their nutrition, so that if, *e. g.*, chloride of zinc is placed on the wound, or introduced into the nutritive solution in sufficient quantity to convert the whole of the albumen into zinc albuminate, the latter would resist decomposition by fungoid matter for a long time. Thus, *e. g.*, Amuat, in his experiments for preventing the putrefaction of pancreas, used, for 30 grams of the latter, 300 grams of a 1 per cent. solution of chloride of zinc. There is no doubt that the 3 grams of chloride of zinc employed were more than enough to coagulate the albumen contained in 30 grams of new glanders. In order to test the action of chloride of zinc in arresting the development of germs, Koch made the following experiment. He added to 10 c. c. of the serum of blood a solution of chloride of zinc, so that the total liquid contained 1 per cent. of chloride of zinc; a second quantity of serum was treated so as to contain 5 per cent. of chloride of zinc in the total solution. Silk threads, with the spores of the splenetic-fever organism, were then introduced into the solutions and examined under the microscope. After the lapse of twenty-four hours the spores contained in both vessels had grown to threads, their vegetation having been the same as that observed with the substances serving to control the tests. It is not stated whether the quantity of chloride of zinc employed was sufficient to precipitate the whole of the albumen and retain an excess of chloride of zinc in solution. If, however, as appears probable, the quantity of chloride of zinc was only large enough to throw down the whole of the albumen contained in the serum, the experiment has no meaning. The chloride of zinc is decomposed into hydrochloric acid and zinc albuminate, and it is easily conceivable that the spores have grown to threads, having found enough nourishment in the unprecipitated portion of the albumen, and in the remainder of the

constituents of the serum. From a similar reason corrosive sublimate, which, according to the researches of Buchholtz, surpasses all other antiseptics when added to solutions of albumen, is converted into mercury albuminate, and no longer possesses the same antiseptic properties which characterize chloride of mercury. Koch injected 1 gram of a 1 per cent. solution of corrosive sublimate into a Guinea pig, and inocculated it on the same day with splenetic-fever bacilli. The next day the inocculated places were much reddened and swollen. The Guinea pig then received, on the morning of the second day, 2 grams of the same solution of corrosive sublimate. According to Koch's estimation, this quantity would be sufficient to prevent the growth of bacilli in a nutritive solution equal in weight to the whole body of the animal experimented with. The animal, nevertheless, died during the following night, from splenetic-fever. The explanation of this is very simple. The 3 milligrams of corrosive sublimate injected into the pig were sufficient to convert only a small portion of the soluble albumen into mercury albuminate. As the latter is readily soluble in an excess of albumen, and also in solutions of common salt, and is not a direct poison for micro-organisms, the injected solution of corrosive sublimate could not exercise any influence over the inocculated splenetic-fever bacilli.

In the course of my investigations I have tested the antiseptic action of another antiseptic agent, the use of which for surgical purposes, although considerable at first, has been abandoned, viz., iodoform and the chemical compounds related thereto. As the pancreas and the liver of animals contain large quantities of micro-organisms, and the soluble ferments contained in the glands of the stomach promote putrefaction, I used the pancreas of oxen, as being the most reliable criterion of testing these substances for their capability of arresting the development of germs. 20 grams of pancreas and 2 grams of iodoform were added to 100 grams of water; the mixture was well shaken, and allowed to stand at a temperature of from, 35° to 38° Centigrade, the whole had a strong odor of iodoform. After twenty-four hours' standing the pancreas became putrid, as though it had been in pure water. The experiment was then repeated with the following modification: 10 grams of perfectly fresh pancreas was intimately mixed with 2 grams of iodoform, and treated with enough water to cover it and prevent it from drying. The temperature was 35° to 38° Centigrade. After the lapse of twenty-four hours this mixture became as putrid as the first. As, according to the opinions of most experimentalists, iodoform, when applied to wounds, acts as an antiseptic, inasmuch as it is gradually decomposed with the liberation of iodine, and the latter is the real active agent, I tried to replace the iodoform by carbon tetri oxide, CI_4, a substance prepared a few years ago by Gustavson. Its preparation in a pure form and on a large scale was, however, very troublesome. I have, on the other hand, examined the antiseptic action of the three carbon chlorides, viz., carbon dichloride (C_2Cl_4) carbon hexachloride (C_2Cl_6), and carbon tetrachloride (CCl_4). Experiments were made also with the two bromotoluenes—the solid and liquid—with pyrogalloldimethylether and paracresol. The results, which are illustrated in the subjoined Table, show that cresol only arrests the development of fungoid germs, its action being equal to that of phenol. The other substances, which were used in the proportion of 1 to 100 of water, were perfectly inactive. In these experiments 20 grams of pancreas were treated with 100 grams of water, and digested with the substance under examination at 35° to 38° Centigrade.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—At the meeting of the Society, held Oct. 7, the Secretary announced the appointment of Mr. L. G. F. Bouscaren, Mr. Robert Moore and Mr. W. Howard White, as a board of censors to award the Norman Medal; the board to award the Rowland prize, will be Mr. Mendes Cohen, Mr. E. P. North and the Secretary of the Society. The deaths of Wilmon W. C. Sites, Member, and Thomas C. Durant, Fellow of the Society were announced. The members of the Society adopted by letter-ballot a resolution, presented at the Deer Park Convention, appointing a committee of five members to consider and report to the Society on the proper relation which the form of the head and rail should bear to the section of a car-wheel tread and flange.

The paper of the evening was read by Mr. Edward Bates Dorsey, it being a supplement to

his paper on "English and American Railroads Compared," presented at the Annual Convention of June 24. In this supplement Mr. Dorsey compared in detail the operating expenses of the systems of England and the United States. In point of traffic it seems that the American railroads average more than double freight, and only eleven per cent. less passenger traffic than the English. The Boston and Albany R. R. is shown to have a larger passenger and freight traffic than any of the large trunk lines of England.

The following gentlemen were declared elected to the classes named.

For Members—William Price Craighill, Lieut.-Col. of Engineers, U. S. A., Baltimore, Md.; Hiram Stevens Maxim, Managing Director and Mechanical Engineer of the Maxim Gun Co., London, Eng.

For Juniors—Bernard Frank Booker, Brooklyn, N. Y; formerly engaged upon Atchison, Topeka and Santa Fé R. R., and recently Division Engineer, Tampico Branch, Mexican Central R. R.; Thomas John Brereton, Maintenance of Way Department, Pennsylvania R. R., Altoona, Pa.; Joseph Maxwell Carrere, New York Steam Co., New York; recently engaged upon Burlington and Missouri River R. R.; Charles P. Matlack, City Engineer, San Antonio, Texas; formerly engaged with Keystone Bridge Company, on United Pipe Lines, Bradford, Pa.; on International and Great Northern R. R., Texas; on Mexican National R. R.

ENGINEERING NOTES.

MAXIMUM WIND PRESSURE.—During the hearing by the Parliamentary Committee, of the case for the promoters of the Tower Bridge over the Thames, Mr. B. Baker, who was called to prove the stability of the proposed structure, gave evidence upon the phenomena of wind pressure as observed by him in connection with the construction of the Forth Bridge. Mr. Baker stated that, from recorded observations in the Firth of Forth, extending over many years, he has come to the conclusion that no pressure at all approaching 56 pounds per square foot can prevail over a surface of any magnitude. He declared that no such pressure has for many years occurred in the Thames valley, instancing, in proof of this assertion, the number of large gasholders scattered up and down the river side. If a hurricane of 56 pounds to the square foot had encountered any of these structures, Mr. Baker believes they would have been doubled up and blown across London, as they have no power of resistance to external pressures beyond the pressure of the gas from within, which he values at not more than 18 pounds per square foot. If, therefore, not the slightest damage of any kind has ever been done by wind to any of the London gasholders, which is a fact, it is a demonstration that they have never been exposed to a pressure of 56 pounds per foot. It is Mr. Baker's experience at the Forth Bridge works that a gale, registering by his improved instruments not more than 16½ pounds per square foot, completely stops all ordinary traffic on the estuary, preventing the running, even, of powerful ferry-boats. Mr. Baker believes that this pressure is rarely exceeded. He declines to place credit in ordinary anemometer readings, which sometimes show extreme velocities, and he points out that trains do not cease running in gales when anemometers will register 46 pounds pressure to the foot, though a pressure of 40 pounds of wind per square foot on its exposed side would certainly upset an ordinary train.—*Engineering News.*

A PIECE of very rapid well-boring is reported by Messrs. Le Grand and Sutcliff, at Brick Kiln Farm, Wolverton, near Stony Stratford, where they bored 50 ft. of artesian boring, of 5 in. diameter, in a single day of eleven hours. Previous to this, they say, 40 ft. was the greatest depth reached in one day.

LIEUT. HILLIARD, navigating officer of the Orion, has made a long and careful survey of the entrance to Alexandria. He finds that the channel to the east of the present Boghaz Pass requires very little deepening, by dredging or dynamite, and the ground being soft the expense would be small. The channel would be available night and day, and is desirable especially for the English Navy. As at present, the Orion is the only large ship of the Mediterranean fleet able to enter the harbor.

A NEW trans-Alpine line, the St. Bernard Railway, is likely to be commenced before very long, and to be, when completed, a dangerous competitor for the through traffic with the already existing route of St. Gothard. One of the principal features of the new project is that the indispensable tunnel under the Alps—at the Col Ferret—will be very much shorter than any other, either constructed or proposed to be constructed. The length will be only 9½ kilometers (5¾ miles), while the St. Gothard tunnel is 15 (9¼ miles), the Mont Cenis 12, and those under the Simplon and Mont Blanc 20 and 19 kilometers respectively. The total length of the St. Bernard line will be but 138 kilometers, or 86 miles, making a saving between London and Brindisi over the St. Gothard route of 59½ miles.

AT a recent meeting of the Berlin Physical Society, Dr. König produced a new apparatus for the measurement of the modulus of elasticity, which was constructed according to the suggestions of Herr von Helmholtz, and was utilized in the Institute for measurements of elasticity. The modulus of elasticity was determined by loading in the middle a bar of the substance to be examined, resting both ends on firm supports. The flexion which set in was measured by means of the cathetometer, and, its value being introduced into the formula of the elasiic theory, furnished the modulus of elasticity. A source of error in these measurements arose from the circumstance that the bar resting on edges was in part pressed in and sank, as a whole. This depression was the greater as the loading was greater, and it added to the magnitude of the deflex. To avoid this disturbance in the account, Professor Kirch-

koff, in 1859, placed horizontal mirrors on the two ends of the bar, and, by means of telescope and scale, observed at each side the change in situation of each mirror, a change which occurred in consequence of the deflexion under the loading in the middle, and which produced on both sides an opposite displacement of the scale. The sinking of the bar on account of the pressure on the edges, and even a slanting position on the part of the whole bar, exercised no influence in these measurements. The apparatus suggested by Professor von Helmholtz developed this principle still further. It had two perpendicular mirrors, with the reflecting surface directed inwards at the two ends of the bar; on one side stood a scale, on the other a telescope. The image of the scale fell on the opposite mirror, then on the second mirror, and thence into the telescope. If, now, the bar were loaded so that deflexion occurred, then the image in the telescope became displaced to the extent corresponding with the angular changes of the two mirrors. By glancing, therefore, into the telescope, the whole amount of deflexion might be very rapidly and conveniently measured, and the loading altered at pleasure. The commencement of the elastic after-effect might likewise be directly observed with great facility.

PROBABLY few cities on the Continent have such a complete, and yet so novel, service of tramways as the free city of Hamburg. Scarcely a strasse of any importance is without its steam or horse tramway, whilst in a great number of the streets in Hamburg and Altona the peculiar feature is the adoption of a vehicle that can be run either upon the tram-lines as a tramcar, or upon the ordinary road as a carriage. The conveyance in question has five wheels: four ordinary coach-wheels, with a radiating leading axle, when used upon the paved roads, and when used upon the tram-lines a small flange wheel, under the control of the driver, is lowered upon the rail, when by its flange running in the groove of the rail, the car is kept on the metals, and assuming the curves to be properly constructed, no difficulty is experienced, whilst in the event of any obstruction upon the line, the matter of diversion of the car is exceedingly simple. There are three different tramway companies in the city, the most recent one being the Hamburg, Altona, and North-Western Tramway Company. Until recently, this company's terminus was the Millernthor, near St. Pauli, some distance from the center of the city. This state of things will, however, soon cease to exist, the company having obtained a further concession, which will enable them to run their cars to the Rodins Markt, the necessary works of line construction, depots, now being carried out by the contractor, Mr. John Fell, of Leamington; the engineer of the company being Mr. E. Pritchard, M. Inst. C. E.; and when completed, it is confidently assumed, a great increase in the receipts will be the result.

AN American contemporary gives an account of a great irrigating canal scheme now in progress in Merced County, California. Merced, the capital of the county, lies in the heart of the San Joaquin Valley, which has been for some years the chief wheat-producing section of the State. The valley extends from the Sierra Nevadas on the east to the skirt of the coast range on the west, its greatest width being ninety miles, and its length from north to south about forty miles. The town of Merced is expected to make enormous strides when the canal is completed. The first side of the ditch suggests the earthworks of a fort, the ground being ridged up from 6 ft. to 8 ft. There are 300 men at work on the canal. The undertaking was begun on March 14th, 1883, and has been carried on continuously ever since. The canal will run across the country from the Merced river just above Snelling to Plainsburgh, ten miles below the city of Merced, on the Southern Pacific Railroad. The slope during this whole distance is a gradual one, and the canal is carried well up on a slight elevation, so that without artificial means the water will flow over the wide extent of level valley land which is to be irrigated. The entire length of the canal will be thirty-five miles, of which sixteen miles are now completed. In the portion which has been built there is one tunnel a trifle over a mile long, and another of 1600 ft. is now being excavated. The general grade of the canal is 1 ft. to the mile. Among the hands employed are 150 Chinese, who are excellent workmen. They receive $1 a day and board themselves, while the white men receive $20 a month and their board. The Chinese live in a camp by themselves and run their own commissariat. The company who have charge of the enterprise have expended already $700,000, and it is roughly estimated that the entire cost of the work will be double that sum.

THE *Petit Marseillais* says that the underground telegraph line from Paris to Lyons and Marseilles is completed, and the wires will be used as soon as the instruments destined for them are placed in the offices at Paris, Lyons, and Marseilles. Underground lines will also be laid between Marseilles, Toulon, and Nice. Marseilles and Havre are already connected by a direct wire, and this not only secures rapid communications between the two ports, but places Marseilles in direct connection with the United States, as the Marseilles-Havre wire is to all intents and purposes the prolongation of the Franco-American cable which abuts at Havre.

ACCORDING to American advices, the Panama Canal Company is in difficulties. Some time ago a New York Engineer was sent to Panama to examine into the affairs of the Canal Company in the interests of a New York syndicate, who proposed to contract for building the canal. It is sufficient to say that his advice was to wait for the crisis which was near at hand. Up to September, 1884, M. de Lesseps and his company had raised 111,000,000 dollars and expended 104,000,000 dollars, their liabilities being 153,000,000 dollars, their securities being sold at a discount. May 1st, 1885, less than 10 per cent. of their excavation, or 12,376,500 cubic meters, had been completed, the total being estimated at from 125 to 150 million meters, and there is the dam for the Chagres

river, for which no foundation has been found after boring to the depth of 60 ft. The entire cost of the canal is estimated at not less than 530,000,000 dollars, representing liabilities amounting to 600,000,000 dollars. The *Financial News* estimates that upon this scale of liability there will be an annual deficit of ten millions of dollars.

IRON AND STEEL NOTES.

THE ROLLING QUALITIES OF HIGH PHOSPHORUS STEEL.—One of the points in connection with the Clapp-Griffiths process which has caused prominent engineers to hesitate in adopting it, has been the doubt as to the practicability of rolling high phosphorus steel. A test recently made at the Edgar Thomson Steel Works has, therefore, particular interest. Two 14-inch ingots from the Oliver plant were charged into a hot furnace, and after remaining in it for two and a-half hours, they were given four passes on the blooming train. The steel rolled exceedingly well, the reduction on the first pass being 2 inches, and on the second 1¼ inch. After being rolled to 10½ inches square, the ingots were taken to the forge, and were reduced to 2½-inch by 14-inch slabs. The experiment, which was made to ascertain whether the steel would stand the heavy reductions of regular blooming mills, was entirely satisfactory. The chemical composition of the steel was: Phosphorus, 0.318; carbon, 0.1; manganese, 0.648; sulphur, 0.047; silicon, 0.008 per cent. We understand that on one occasion, by an accident, no manganese was added to the charge, and yet the steel rolled well, and since then steel has been made without adding ferromanganese, which rolled as well as steel made in the ordinary way.

RAILWAY NOTES.

THE EXPANSION OF RAILS BY HEAT.—Major Marindin, in his report to the Board of Trade on the causes of the accident which occurred on August 2, on the Great North of Scotland Railway, between Martle and Inveramsay stations, states that the accident was due to the distortion of the line, the rail on the right side (and according to one witness, the corresponding rail on the left side) being bent for over an inch at a point 42 feet behind the mark of the wheel flange on the left rail. As there was no defect in the engine, and the driver's estimate of the speed—viz., 25 miles an hour—is probably correct, Major Marindin can only attribute the distortion of the rail to an expansion of the metal from the heat of the sun, as it is in evidence that the sun was exceedingly hot upon the day in question. He considers that the only way of guarding against such accidents as this would be by having a midday examination of the line in exceptionally hot weather, especially upon lines where the permanent way is not of the heaviest type. It will be remembered that in this accident, as the 12.25 P. M. up passenger train from Macduff to Inveramsay was running down an incline of 1 in 177, about 1¼ mile north of Inveramsay, one of the carriages, probably the second from the engine, left the rails. The train was running at a speed of about 25 or 30 miles an hour, and the engine ran for about 235 yards before coming to a stand, when it was found that the leading wheels of the leading carriage were off the rails, the second carriage was upset on its right side, the third was off the rails across the line, and the rear vehicle, a break van, had broken away from the train, and was lying against the bank on the left side of the line, about 147 yards behind the rear passenger carriage. The couplings between the tender and leading vehicle were not broken, but the screw couplings between the first and second, second and third, and third and fourth vehicles were broken, and the side chains between the first and second vehicles were loose, between the second and third were holding, and between the third and fourth were broken at the hooks.

THE number of tons of freight transported on American railroads in 1884 equaled 390,074,749, against 400,453,439 tons in 1883, the falling off equaling 10,378,690 tons, the rate of decrease being about 2½ per cent. The value of the tonnage moved in 1884, estimating its value at $25 the ton, equaled $9,751,868,725. The number of tons transported one mile in 1884 equaled 44,725,208,277 tons, against 44,064,923,445 tons moved one mile in 1883, the increase of service performed for the year equaling 660,284,288 tons moved one mile, the rate of increase being about 1½ per cent.

AN American contemporary says: "The Pike's Peak Railway, which is expected to be in operation this year, will be the most notable piece of track in the world. It will mount 2,000 feet higher than the Lima and Oroya Railway, in Peru. It is now in operation to a point over 12,000 feet above the sea level. The entire 30 miles of its length will be a succession of complicated curves and grades, with no piece of straight track longer than 300 feet. The maximum grade will be 316 feet to the mile, and the average grade 270 feet. The line will abound in curves from 500 to 1,000 feet long, in which the radius changes every chain."

THE rates per ton per mile for 1884 of freight carried on the United States Railways equaled 1.124 cent, against 1.236 cent for 1883, the falling off equaling 1.12 mill per ton per mile. Had the rates for 1883 been maintained for 1884, the earnings from freight would have been $553,694,042, in place of $502,869,901, the amount actually received. Had the rates of 1883 for the transportation of passengers and freights been maintained for 1884, the gross earnings of all the roads would have been $827,525,371, exceeding by $56,840,463 the amount actually received, and greater, by $3,752,447, than the earnings for 1883. It will thus be seen that the decline in the earnings for the past year was due wholly to the reduction in rates charged.

DURING the six months ending June 30th, 435 failures of tires and 169 failures of axles took place on British railways. Of the 435 tires which failed, 9 were engine tires, 8

were tender tires, 2 were carriage tires, 7 were van tires, and 409 were wagon tires; of the wagons, 307 belonged to owners other than the railway companies; 388 tires were made of iron and 47 of steel; 11 of the tires were fastened to their wheels by Gibson's patent method, 6 by Mansell's, and 1 by Beattie's, none of which left their wheels when they failed; 410 by bolts or rivets, two of which left their wheels when they failed, and seven by other methods, one of which left its wheel when it failed; 16 tires broke at rivet holes, 5 in the solid, and 362 split longitudinally, or bulged. Of the 169 axles which failed, 99 were engine axles, viz., 86 crank or driving, and 13 leading or trailing; 6 were tender axles, 2 were carriage axles, 60 were wagon axles, and 2 were axles of salt vans. Twenty-nine wagons, including the salt vans, belonged to owners other than the railway companies. Of the 86 crank or driving axles, 66 were made of iron and 20 of steel. The average mileage of 66 iron axles was 229,569 miles, and of 20 steel axles, 202,715 miles.

THE number of persons transported in 1884 by all the American lines was, according to *Poor's Manual* 334,814,529, against 312,686,641 for 1883, the increase for the year being 22,127,888, the rate of increase equaling 7.8 per cent. The number of passengers carried one mile in 1884 equaled 8,778,581,061, against 8,541,309,674 in 1883, the increase equaling 237,271,387 persons carried one mile, the rate of increase equaling very nearly 3 per cent. The distance traveled by each passenger in 1884 equaled 26.24 miles; in 1883, 27.32 miles. The amount received per passenger per mile equaled 2.356c in 1884, against 2.422c. in 1883. Had the passenger rates for 1883 been maintained for 1884, the earnings from this source would have equaled $212,617,233—a sum $5,826,532 greater than that received

THE FIRST FRENCH RAILWAY.—In two years' time France will celebrate the jubilee of the establishment of railways. The first French railway—that from Paris to Saint-Germain, which became the nucleus of the Great Western of France—was opened on August 27, 1837. Its construction was sanctioned just fifty years ago. The late Emil Péreire undertook to make this line of 18 kilometers (10 miles) at his own cost and risk. It had taken nearly three years to obtain the consent of the authorities, the contention of Thiers being that railways could never be more than a mere toy, while Arago also doubted their utility. The requisite capital of 6,000,000 francs was not easy to raise, although two bankers, Eichthal and Thurneyssen, had deposited the 200,000 francs caution money; but the difficulties were surmounted when Péreire won over the Rothschilds and Samson Davilliers. France has now 31,000 kilometers (19,220 miles) of railways, conveying 180,000,000 passengers a year, and the gross receipts are 1,150,000,000 francs. Two hundred and twenty-three thousand persons are employed on these railways, and the State derives a revenue of 83,000,000 francs from them.

THE approximate weights of the fast trains on the New York division of the Pennsylvania Railroad are given as follows by the St Louis *Railway Register*:—Engine, ready for service, 96,700 lbs.; tender, ready for service, 56,300 lbs.; two men on engine, 300 lbs.; one combined car, 30,000 lbs.; one parlor car, 50,000 lbs.; two passenger coaches, 80,000 lbs.; 140 passengers, estimated 21,000 lbs.; total, 342,300 lbs. Coal, estimated 5,000 lbs.; water, 3,700 gallons: average schedule speed, 48.01 miles; maximum schedule speed per hour, 55.08 miles; distance from Jersey City to Philadelphia, 89.06 miles.

THERE appears to be a basis of fact for the *National Zeitung's* assertion that the Chinese government has at last decided to adopt a "forward policy" in regard to railways, and that a contract has been signed with a Manchester firm for making a line from Taku to Tong-Chow. This firm has undertaken to supply the material and the rolling stock, while the Chinese government is to furnish the capital and the labor. The construction of the line will be left in the hands of the Manchester firm, which will also work it when open. The loan of 100 million florins, for which the Chinese government is now negotiating with several Dutch and German banking houses, is doubtless, thinks the *National Zeitung*, connected with this project. The London *Times* and other journals have lately been eloquent on the grand future for enterprise in China.

ORDNANCE AND NAVAL.

AN important addition is made to the unarmored fast cruisers of the Royal Navy by the launch on the Medway of the new steel cruiser Severn, twelve guns, 3,550 tons, 6,000 horse-power. The Severn, which has been built at Chatham Dockyard, is a more powerful vessel than the cruisers of the Leander type, and will also possess a greater steam power, her engines being estimated to produce an additional indicated horse-power of 1,000. The vessel will be mounted with twelve 6-in. steel breech-loading guns, on the Vavasseur system, twelve Gardner and Nordenfelt machine guns, and Whitehead torpedoes.

IT is said that a new substance for ships' armor has been satisfactorily tried. It is obtained from cocoanut cellulose, and has the property, when penetrated by shot and shell, or even after the explosion of a torpedo, of closing up as rapidly as it has been perforated, and thus preventing the influx of water into the ship's hold. Some important experiments have lately been made with the composition before a French commission at Toulon. The commission submitted the composition to a three-fold test: against shot, shell, and torpedo. The target was a cofferdam, made of a mixture of fourteen parts of pulverized cellulose, and one part of cellulose in fiber. This composition was compressed to a felt-like mass, of which one cubic meter weighed 120 kilograms, or one cubic foot—about 8 lbs. A layer of beams 4¾ in. thick represented the side of the ship, behind which there was a layer of the new material 2 ft. thick. Against this target a 7½-in. solid shot was fired, which pene-

trated it, taking with it not quite one-fifth of a cubic foot of composition—a very small quantity, considering the size of the shot. But as soon as the shot had passed through the target the cellulose composition closed up again, and so firmly that a strong man was unable to force his arm through the opening made. A box filled with water was then fixed against the aperture, the contents of which ought to have acted in the same way as if the cofferdam had been washed by the sea. It was observed that a few drops of water began to percolate after the lapse of from ten to fifteen minutes, and even after the composition had become well saturated with water, only between three and five pints of water escaped per minute, which could easily be intercepted by pails. As soon as the cellulose had become thoroughly soaked and grown denser it offered greater resistance to the percolation of water, which finally almost ceased to flow.

A Scandinavian correspondent writes that in the early part of September some important experiments were to be carried out in the Sound, with the last engine of torpedo warfare, constructed by M. Nordenfelt, viz., a submarine torpedo boat, built at Karlsvik, near Stockholm. "This terrible adjunct of our modern destructive warfare is fitted with engines indicating 100-horse power, and will, it is said, easily attain a speed of fifteen miles an hour above, and thirteen miles below, the surface of the water. When the boat is about to attack a hostile vessel, she is sunk to the required depth by the admission of water into tanks, but it is only intended to be submerged to the depth of a foot or two when about to attack. On catching the shadow on the water of the unsuspecting war ship, the Whitehead torpedoes, with which she is equipped, are discharged against the bottom of the vessel, which will have the effect of sinking her. When the work of destruction is complete, the boat re-emerges from the water by the operation of special automatic machinery. The hull itself, which is constructed of Swedish soft steel, of a minimum thickness of ½ in., is of the cigar pattern, and is only with difficulty visible, even when floating on the surface. The length of the boat is 64 ft., and the diameter about 8 ft., the engine room being 7½ ft. in height, and the gross weight of the whole vessel when fully manned and equipped is 60 tons. A sort of bell-shaped glass cupola rises from the center of the boat, into which the steersman puts his head when under water, thus commanding an all-round view, and enabling him to direct the general movements of the craft. In case of accident, the vessel is divided into water-tight compartments, and extra pumping machinery is provided, to be used in the event of any portion of the automatic machinery failing to raise the vessel to the surface. The crew consists of three men, and the armament of four torpedoes, two being of the "fish" pattern, and two of the ordinary spar kind. Against such an insidious foe as the boat constructed by Nordenfelt, it is obvious that the ordinary wire netting for the defence of ironclads from the hitherto employed torpedo boats will be useless; and if the boat fulfills expectations, warfare with our present huge vessels promises to be in serious jeopardy."

Gunnery Experiments.—The authorities of the War Department desire to have it known that the damage done to a gun during the recent experiments with high explosives at Lydd was due to no fault of the gun, but to the explosion inside the bore, of a shell charged with the most violent of all explosive agents—blasting gelatine. The object of the experiments was to ascertain how far the tendency of such like varieties of the nitro-glycerine series to detonate on slight provocation could be brought under control, it being very desirable, if practicable, to use something more powerful than gunpowder for shell charges. The dangerous compounds were therefore packed and padded as carefully as possible in their shells, in the hope of overcoming or reducing the concussion of discharge when the gun was fired; but it was known that premature bursts were likely to occur at any moment, and it was also known that if one of the shells burst within the gun, however strong the gun might be, the gun must "go." So far as the results are allowed to transpire, it may be inferred that very few of the shells remained intact until they reached the target. Several broke up after leaving the muzzle, and one charged, as aforesaid, with blasting gelatine, burst inside, with the natural consequence of destruction to the gun. As the experimental committee have been congratulated on the absence of accidents, it may also be said that in all such hazardous investigation they keep well under cover and fire the guns by electricity. For some time past it has been the practice at Woolwich Arsenal to try test tubes of steel, an inch or so in diameter, to prove the quality of the metal, the artillerists being in want of a lining for their guns which shall resist the erosive action of the powder and projectiles, and some of these have failed at proof. This, also, has given rise to a report that guns have burst at the proof butts, and this report the authorities wish likewise to correct by this explanation.

Ten and Twelve-inch Armstrong Guns at Cadiz.—Major C. Jones, late R. A., gives an account in the current number of R. A. "Proceedings" of a trial of 10-in. and 12-in. guns supplied by Elswick to Spain, which took place at Cadiz, last December. It is not necessary to give all the details, because the guns, which were put in hand in 1882, are not of the newest pattern. They are both breech-loaders, made of steel and coils of iron, with Elswick obturators. The 10-in gun weighed 26 tons, the 12-in. 43 tons, having barrels something over 25 calibers long. The projectiles weighed 400 lbs. and 700 lbs. respectively, and were fired with charges of 200 lbs. and 310 lbs., having muzzle velocities of 2,025 and 2,000 feet-seconds and 11,374 and 19,415 foot-tons muzzle energy. Calculated perforation at muzzle, 19.5 in. and 23.5 in. of iron.

The mounting, and security of pivot and foundations having been tried, chilled projectiles were fired at armor targets. The back of the target before it was made up for firing,

had a sand-bag butt to prevent movement of the target and to stop the shot. The target consisted of four thicknesses of plates, each 10 c.m. (3.94 in.) thick, 15¾ in. in all, backed by 25 in. of wood, to which it was bolted. The 12-in. gun fired three rounds at this structure, of which the following table gives the details:

Round.	Weight of charge.	Weight of chilled projectile filled with sand.	Striking velocity at 246 yards.	Recoil.	Range represented by striking velocity.	Penetration.
	lbs.	lbs.	ft. per sec.	Inches	yards.	
1	220.0	690	1575	41.5	2950	Through target and about 18 ft. into sand butt.
2	220.0	695	1588	41.5	2850	Ditto.
3	154.3	689	1440	27.0	4080	Through target and about 10 ft. into sand butt.

The three projectiles struck the spots aimed at exactly, the plate being as shown in the table, 225 meters—246 yards—from the muzzle of the gun. The three projectiles were dug out from the sand at the back of the target. The first two were entire, the third one was partly broken. That the 12-in. gun shot with 1,575 ft. velocity should perforate 15¾ in. in four layers is only to be expected. The projectile having a sectional density expressed by $\frac{W}{D^3}$ =0.4, the rule of thumb of 1 caliber perforation for every 1,000 ft. velocity holds good very nearly—that is, the perforation due to 1,575 ft. velocity is not far from 18.9 in. It actually works out 18.3 in. for a single plate, and for one made up to four thicknesses, 20 in. The projectiles were therefore sure to perforate. The noteworthy feature is that they held together so well after perforation. They were selected haphazard from the supply, and therefore show that at Elswick a remarkably high degree of excellence has been reached in chilled or Palliser projectiles. The same thing has taken place at Woolwich. It is not a matter of unqualified satisfaction to us to notice this, because we fear it tends to keep back the development of steel shells. So long as soft iron armor is fired at, the most excellent steel can offer hardly any advantage over chilled iron for projectiles, beyond that of holding better together after perforation is accomplished. Even against some steel-faced armor or very soft steel, it appears questionable if steel shells offer any commensurate advantage for their great cost. Unfortunately, against really hard armor we have reason to believe that chilled iron could not compare with steel at all, and this class of armor is seldom fired at in this country

To return, however, to the Elswick guns, we have only to add that the trial is reported as satisfactory in all respects. The feature that chiefly strikes us is the excellence of the projectiles.

THE NEW TORPEDO BOATS.—A large sea-going torpedo boat, the first of the series of forty which the country owes to the recent popular agitation on "The State of the Navy," was tried in August in the Thames. The vessel has been built by Messrs Yarrow & Co., of Poplar, being one of twenty that the government has ordered of that firm. The trial was, according to present regulations, for two hours' continuous steaming at full speed, and during that time, and as nearly as possible in the middle of the two hours, six runs were made on the measured mile. A mean speed of 19¼ knots was realized, 19 knots being the guaranteed speed, with an air pressure in the stokehold of only 3¼ in., as shown by the air gauge. The boat is 125 ft. long, 13 ft. wide and 8 ft. deep. She has, naturally, far more accommodation than the first-class torpedo boats hitherto constructed, being able to berth well a crew of twelve or thirteen men forward, whilst there is comfortable room for the officers aft. Special care has been taken to provide efficient ventilation in the new boats, and it is hoped that the great discomfort hitherto found when at sea for any lengthened period will be materially reduced. There is one tube forward for ejecting torpedoes right ahead, and arrangements are made for firing four torpedoes from either side, or two from one side and two from the other at the option of the officer in charge. The number of torpedoes carried will be five, one in the bow gun and four in four guns for side firing. It will thus be seen that there are five torpedoes all ready to be discharged at a moment's notice. This is considered a far better arrangement than hampering the boat with a number of spare torpedoes, of which none will be carried. There will also be two machine guns, one being placed on the top of each conning tower. There are two conning towers, one forward and the other aft. Provision is made for steering the vessel from either of these towers, so that should one get damaged in action the other will be available. The four side-firing torpedo guns are fixed two to each conning tower in such a manner that they can be made

to revolve so as to secure any angle of fire, which plan was originated by the authorities of the Vernon. The impulse by compressed air is to be superseded by the simpler and equally efficient system of ejecting by gunpowder The engines are of the usual type fitted by Messrs. Yarrow in vessels of this class, the cylinders being 14½ in. and 26 in. in diameter by 16 in. stroke. The boiler is of the locomotive type, and contains the usual special features introduced by Messrs. Yarrow & Co. for torpedo boat work. The total heating surface is 1,200 square feet, and the grate surface, 30 square feet. The indicated horse-power on trial was not accurately obtained, but is estimated at 700, the steam-pressure being 123 lbs., and the engines running at 376 revolutions a minute. It was noticeable that throughout the two hours' trial the speed of the engine only varied within the small limits of 1½ per cent. more or less than 376. It is estimated that sufficient coal can be carried for a continuous run of 2,000 knots at a speed of ten knots an hour, the bunkers holding about twenty-three tons. This most recent addition to our torpedo fleet would undoubtedly prove a very formidable antagonist at sea, being sufficiently powerful to operate in any reasonable weather. She is the result of the accumulated experience of several years, and the country is to be congratulated in having got her and her sister vessels well to the fore before they are actually wanted.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

TIDAL Theory and Tidal Prediction. By E. A. Gieseler. Pamphlet.

The Minting of Gold and Silver. By Albert Williams, Jr.

Placer Mines and Mining Ditches. By Albert Williams, Jr.

Proceedings of the Institution of Civil Engineers:

No. 2044.—The Signaling of the London and North Western Railway. By Arthur Moore Thompson, M. Inst. C. E.

No. 2064.—The Copper Mines of Butte City. By David William Brunton, M. Inst. C. E.

No. 2069.—Rivers Flowing into Tideless Seas. By William Shelford, M. Inst. C. E.

No. 2084.—Spanish Tidal Flour-Mills. By Alexander Fairlie Bruce, Assoc. M. Inst. C. E.

No. 2097.—The Semi-circular Timber Roof-Truss. By Gilbert Richard Redgrave, Assoc. M. Inst. C. E.

LECTURES ON THE PRINCIPLES OF HOUSE DRAINAGE. By J. PICKERING PUTNAM. Boston: Ticknor & Co. Price 75 cents.

There are three parts to this compact little work. The first part deals with Traps exclusively. Good and bad forms of construction are described; the evils to be avoided, and the way to avoid them, are presented and illustrated by good diagrams.

Wash-basins and Water-closets are fully described in the second part. The illustrations are numerous and good.

Part three deals with Soil and Drain Pipes. First, the materials are considered, and then the methods of jointing. The illustrations of this subject are not so numerous, but evidently sufficient for the purpose.

The work will prove valuable to builders or house designers.

THE MATHEMATICAL THEORY OF ELECTRICITY AND MAGNETISM. By H. W. WATSON, F. R. S. and S. H. BURBURY, M. A. Vol. I. Oxford: Clarendon Press.

The authors regard this treatise as an introduction to, or commentary upon, Clerk-Maxwell's work, and is, therefore, more widely useful to the average student. By this, however, is meant the student of mathematics, not of applied electricity.

The copies presented in the present volume, dealing with Electrostatics only, are: Green's Theorem; Spherical Harmonics; Potential; Description of Phenomena; Electrical Theory; Application to particular cases; The Theory of Inversion applied; Electrical Systems, in two dimensions; Systems of Conductors; Electrical Energy; Specific Inductive Capacity; The Electric Current; Thermoelectric Currents; Polarization of the Dielectric.

MODERN MOLDING AND PATTERN-MAKING.—By JOSEPH P. MULLIN, M. E. New York: D. Van Nostrand. Price $2.50.

This book is prepared for workmen by an artisan, and, like works of its class, is very concise. The above title is made to comprehend a large variety of acquirements.

The author begins with an essay on the duties of draftsmen, and explains wherein their labors are intimately related to those of the molders.

This is followed by descriptions of the machinery of the pattern shop. Then come Molding Spur Gears, Worm Gears, Sheave Wheels, Fly Wheels and Band Wheels.

Considerable space is devoted to cylinder work of different kinds.

Lathes, Mining Machinery, and Propeller Screws are the subjects of three separate chapters.

The work is illustrated with 165 cuts interspersed throughout the text.

NOTES ON THE CHEMISTRY OF IRON. By MAGNUS TROILUS, E. M. New York: John Wiley & Sons. Price $2.00.

This is a guide for the student who wishes to analyze the ores, products and slags of iron manufacture.

The work is in four chapters, the first of which deals with the elements to be sought for in the finished products. The second chapter gives specific directions for the quantitative determination of all foreign substances found combined in commercial irons and steels.

The third chapter is devoted to the methods to be followed in analyzing ores and slag.

Chapter four is a shorter one, and deals with the analysis of the gaseous products of iron manufacture.

The typography of the book is exceedingly good.

PRINCIPLES OF ECONOMY IN THE DESIGN OF METALLIC BRIDGES. By CHARLES B. BENDER. New York: John Wiley & Sons. Price $2.50.

The method of the author for the comparison of bridge systems is to multiply the strain of each member of a fully-loaded bridge of a fixed number of panels by the length of the member, and add the products. Results thus obtained afford means of determining the relative economy of different designs.

In the present treatise this plan is applied to the framed arch, the cantilever and the stiffened suspension bridges.

As a thoroughly scientific essay upon an important subject, the work will doubtless be welcomed by the profession. It is well to remember that Mr. Bender, although he began his professional career in Europe, is one of the strongest advocates of the American system of iron trusses.

MISCELLANEOUS.

Boiler Steel.—The committee appointed by the American Master Mechanics' Association on boilers reported as follows, on the subject of steel for boilers: "The steel we now easily procure, and should use for both sheet and furnace, has but a small percentage of carbon, say from 15 to 20 per cent., and therefore, if fairly free from silicon, phosphorus, &c., will not harden, is mild and ductile, working under the hammer, even when cold, most freely, has a breaking resistance of from 62,000 to 65,000 lbs. per square inch of section, with an extension of 24 to 25 per cent. in length of 10 inches. A good shop test—in addition to bending over at a point in the test piece where it has been punched, either cold or after it has been heated or dipped in water—is to take a narrow strip through which a hole one-fifth its width is punched, and then enlarge the hole with a drift and flagging hammer to fully three times its original punched diameter without splitting the strip. It may be said that there is now no practical limit to the size that steel sheets of desirable quality and thickness can be procured. The Canadian Pacific Railway are making the straight portion of wagon-top boilers in one plate, and receive $\frac{7}{16}$-inch sheets 14 feet 3 inches by 8 feet, and last year, at Erie Pennsylvania, $\frac{3}{8}$-inch plates 16 feet long were bent cold in rolls to a curve of 30-inch radius, so that two sheets made one boiler 16 feet long and 60 inches diameter, with but two longitudinal joints in barrel; and Mr. Webb has rolled from ingot and used $\frac{7}{16}$-inch steel plate 11 feet 3 inches wide by 12 feet 9 inches long in one barrel ring. This practice is in line with the strong recommendation of the committee in 1871; but, as they point out, it requires special rolls to be built for bending the plate. Mr. G. S. Strong says he is now constructing a 56-inch straight boiler for 175 lbs. pressure, with all longitudinal seams welded. Welded seams, when iron plate and coke fire were used, give, at least, but an ultimate tension of 14 tons and 6½ per cent. extension for 22-ton iron; therefore, it is not a matter of surprise that such a form of joint was seldom used, but now Mr. S. Fox, using 22-ton mild steel and common gas flame for heating the scarf, secures a weld having an ultimate tension of 21 tons and an elongation of 8½ per cent. in a 10-inch length—that is, an increase of 50 per cent. in strength and 30 per cent. in ductility; although it should be noted that this excellent result is but one-third the ductility of the unwelded steel plate. Some careful experiments show that very mild steel, after annealing, loses somewhat in resistance to ultimate tension and in ultimate percentage of extension, or, in other words, annealing does not necessarily improve the natural plate. Nevertheless, if holes are punched in plate, or plate has been flanged or set when warmed, mild steel must be annealed, the annealing furnace temperature not being carried too high—a blood or cherry red is quite sufficient—the time in furnace not prolonged beyond the point that will secure thorough and equal temperature, and the cooling not too much hurried by contact with damp earth or a current of wind at low temperature. Neither should there be any attempt to soften off by cooling in a bed of sawdust or ashes. If the flanging, setting, or any other distortion, such as bending in the rolls can be done cold, there is no necessity for annealing either plates or bars, but all such setting is preferably done under the steady pressure of hydraulic tools." In the discussion on the report there were some objections, but the general opinion held was that steel was the proper material for the interior of fire-boxes.

The following, from the report of the *Astronomer Royal*, are the principal results for magnetic elements for 1884:—Approximate mean westerly declination, 18 deg. 8 min.; mean horizontal force, 3.931 in English units, 1.812 in metric units; mean dip, 67 deg. 29 min. 8 sec. by 9-in. needles, 67 deg. 29 min. 32 sec. by 6-in. needles, and 67 deg. 30 min. 9 sec. by 3-in. needles. In the year 1884 there were only five days of great magnetic disturbance, but there were also about twenty days of lesser disturbance.

The first annual dinner of the University College Engineering Society (London) was held last Tuesday evening at the Holborn Restaurant. The attendance was large. Among others present were Mr. Bryan Donkin, Mr. Rich, Mr. C. E. Stromeyer, and others. Professor Alex. B. W. Kennedy, president of the society, occupied the chair.

The United Asbestos Company is introducing a new lubricant, called the Salamander lubricant, which is offered as applicable for all purposes, and especially so where asbestos packing is used. The following is from the analysis of the lubricant, by Mr. R. H. Harland, F. I. C.:—Mineral matter (ash), .04 per cent.; vegetable and animal oils, none; free acid, none; melting point, 125 deg. Fahr.; solidifying point, 120 deg. Fahr.; flashing point, 384 deg. Fahr. The analysis of this grease proves it to be a pure hydro-carbon, perfectly solid at all ordinary temperatures, and having a melting point of 125 deg. Fahr. It is quite free from the slightest trace of acidity. It is a neutral grease; its consistency, combined with the fact that it will not corrode metallic surfaces, shows that it is a satisfactory material for lubricating. It would answer well with asbestos packing.